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## Original Communications

### DORSAL SYMPATHETIC GANGLIONECTOMY FOR INTRACTABLE ASTHMA


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AT THE beginning of any discussion of bronchial asthma it must be admitted that the pathologic physiology of the asthmatic attack is variable and that many factors probably combine to produce the symptom complex known as asthma. Surgery of the autonomic nervous system for bronchial asthma at present consists of the excision of organs whose function is partially known for a disease the cause of which is not fully understood.

It is the purpose of this paper to touch upon the high spots of known fact and conjecture concerning this syndrome called bronchial asthma and to describe an operation which promises to relieve some of the patients suffering with it while more fundamental researches are being carried on.

Reduction of the bronchial lumen appears definitely to be the modus operandi of asthma. It has been observed by all who use the bronchoscope on asthmatic patients and has been repeatedly observed in bronchograms with iodized oil. However, in our experience these "contracted" bronchi are regularly found in asthmatic patients *between attacks*, leading us to believe that perhaps the bronchi do not contract and relax in response to stimuli from the extrinsic nerves, as has long been supposed. In certain patients, at least, we have shown that the bronchi of all diameters are in a constant state of diminished caliber and that the asthmatic attack depends upon the changing state of the bronchial mucous membrane and bronchial secretions.

The only evidence we have found to indicate that contraction takes place is the observation of Huber and Koessler[1] that some patients with a history of asthma show hypertrophy of the smooth bronchial muscles after death. Hudson and Jarre[2] have demonstrated this chronic reduction of the bronchial lumen


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Originally read before the American Association for Thoracic Surgery at Los Angeles in 1939. Additional observations made upon the original patients and case histories of two more recently operated patients have been added. Publication, formerly withheld because of the small series and relatively brief follow up, now appears justified.



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with iodized oil and the Cin-ex camera, making serial x-ray films in quick succession. Further evidence of the constant nature of the contraction is found in the fact that patients relieved of asthmatic symptoms still show the reduced bronchial lumina. Relief obtained by some patients from irradiation can best be explained by its effect upon the bronchial mucosa.

Lukens[3] describes four types of change in the bronchial mucosa of asthmatic patients; one, a septic tracheobronchitis with abundant mucopurulent secretions adherent to the mucous membrane; two, a chronic catarrhal tracheobronchitis with intensely inflamed mucosa and with a small amount of mucopurulent secretion; three, a cyanotic and swollen mucosa of the trachea and bronchi; and, four, a mucosa with actual urticarial patches. Christopherson[4] describes a condition occasionally observed by us in which the tracheal and bronchial walls have become collapsible so that during forced expiration or coughing a mere slit is presented for the escape of air.

Phillips[5] believes that some metabolic or systemic disturbance conditions the patient to render him susceptible to stimuli in the mouth, nose, throat, ear, or lower air passages, those "trigger areas" supplied by the fifth, ninth, and tenth cranial nerves. The susceptible patient shows an asthmatic response to stimulation of one or more of these areas, whereas the normal individual does not. In support of his belief Phillips reports that a large group of his asthmatic patients shows a low average temperature, a low or low normal metabolic rate, low blood pressure, low blood sugar, high gastric acid level, low urea nitrogen, and high indican level in the urine, and, frequently, a dry, thick or eczematoid skin subject to discolorations. Godard[6] also has noted the low and unstable blood calcium level in his patients with asthma.

The sympathetic ganglia removed by us at operation from asthmatic patients showed histologic evidence of toxic or metabolic degeneration.

All authors agree that the extrinsic nerve supply of the lungs is derived from the vagus and sympathetic trunks from which fibers combine on the posterior surface of the hilum to form the posterior pulmonary plexus. Danielopolu[7] believes that a simple bronchomotor reflex arc exists through the sympathetic (afferent) and vagal (efferent) pathways because "identical results (are) obtained by sectioning two nerves which contain antagonistic bronchomotor fibers." Phillips and Scott[8] state that "much opinion and little fact is presented to prove that the sympathetic is the afferent and the vagus the efferent trunk of a reflex arc." Kummell[9] believes that bronchial constrictor fibers run in both the sympathetic and vagal trunks, the basis for his original cervical sympathectomy for asthma. Levin[10] believes that bronchial constrictor fibers are contained in the sympathetic trunk and describes the pathway through which the sympathetic fibers distributed to the pulmonary plexus by the cervical sympathetics arise in the thoracic segments, showing that the whole bronchial sympathetic innervation is derived from a thoracic source. He observes that vagus manipulations in operations upon the esophagus slow the heart but produce no asthma, and that lesions of the vagus, paralytic or irritative, are not characterized by asthma. Carmichael and Fraser[11] have demonstrated the release of acetylcholine (a depressor and relaxor) about the nerve endings of the

vagus on stimulation, and a substance like adrenin on stimulation of the sympathetic nerves. These observations make it difficult to believe that the vagus is a simple bronchial constrictor. What seems more likely true from the evidence of the several authors is that the vagus and sympathetic trunks contain both sensory and motor fibers and that normal bronchial tone (or normal function of the mucosa and glands) depends upon a balance between them.

Freeman, Smithwick, and White[12] state that "structures which receive their nerve supply from the sympathetic nervous system become more sensitive to adrenin after denervation," as was demonstrated by their work upon the blood vessels of the extremities. Adrenin applied directly to the bronchial mucosa shrinks the membrane and reduces secretions. Applied directly to the smooth muscle it would be expected to produce contraction rather than relaxation. If the bronchial lumina are in a constant state of reduction due to muscle spasm or other cause, sensitization of the mucosa to the patient's own adrenin is a possible explanation for the beneficial effects of sympathetic denervation.

Levin supports his views with a series of twenty-three patients whose dorsal sympathetic ganglia he destroyed by alcohol injections. Complete relief from asthmatic symptoms was obtained in 75 per cent of his patients, with varying degrees of improvement in the remainder. Either sufficient bronchomotor fibers were destroyed to alleviate symptoms or the mucosa and glands were favorably influenced.

Complete denervation of the lung by excision of the posterior pulmonary plexus is unquestionably the most certain method now known for eliminating all extrinsic nerve stimuli. Rienhoff and Gay,[13, 15] report excellent results with this operation in twenty-six cases. However, these patients are frequently very poor operative risks with marked limitation of cardiorespiratory reserve. We feel that a procedure requiring less drastic surgery is to be preferred if comparable results can be obtained. It is also an ideal in surgery to preserve as much normal function as possible while achieving the desired result. For these reasons the apparent logic of Levin's article appealed to us and it was decided to perform a bilateral dorsal sympathetic ganglionectomy upon two patients and to observe the results before proceeding with the operation upon others. The apparent success obtained with the first two patients encouraged us to perform the operation upon the third a year later.

## TECHNIQUE OF OPERATION

The first two operations (the right side of each of the first two patients) were performed according to the technique of Adson and Brown,[14] exposing part of the fourth rib and its transverse process after separating the erector spinae muscles from the dorsal processes of the vertebrae. After resecting the transverse process and about one inch of the rib, the sympathetic trunk was engaged with a nerve hook and brought into view. The third and fourth ganglia were resected. The ganglia lie on the anteromesial surface of the heads of the ribs and are, therefore, not immediately seen from this posterior approach. The field entered is also a very vascular one. We felt that the normal approach of the thoracic surgeon would simplify the procedure.

In the next four operations a crescent-shaped parascapular incision was used, resecting the third and fourth ribs to a point two inches lateral to their angles. The transverse processes were also removed. The cleavage plane external to the endothoracic fascia was developed, pushing the pleura and fascia away from the heads of the ribs. The sympathetic ganglia could then be clearly seen, dissected free of all connecting rami, and excised with the intervening sympathetic trunk. The wound was closed in layers without drainage in all cases. For us the operation was technically much easier to perform and more satisfactory from the standpoint of exposure.

The last four operations were performed similarly except that the second, third, fourth, and fifth dorsal sympathetic ganglia were removed.

## CASE REPORTS

CASE 1.— F. I., a Negro woman, aged 25 years, unattached, entered the John Gaston (City) Hospital Nov. 26, 1935, stating that in 1928 she began to have attacks of wheezing and dyspnea occurring each fall. By 1935 the wheezing was almost continuous, with freedom from symptoms never lasting over a week. No particular food or plant allergies were noted. During five admissions to the hospital and innumerable visits to the emergency room she received treatment with adrenalin, ephedrine, morphine, atropine, pituitrin, potassium iodide, magnesium sulphate, and calcium gluconate. Gradually all forms of medication failed to bring relief. An attempt to isolate the patient from allergenic proteins failed to affect her condition. The patient claimed she had been unable to work since 1928.

Past history was negative except for a Caesarean section and antisyphilitic treatment in 1928.

The family history was negative for tuberculosis, cancer, or evidences of allergy.

Physical examination revealed an old-looking Negro woman sitting up and inclining forward, struggling for breath. All of the accessory muscles of respiration were active. The chest was barrel-shaped and hyperresonant, and auscultation revealed typical râles, rhonchi, and siffles of bronchial asthma. The remainder of the physical examination was of no especial interest. None of the abnormalities of the upper air passages frequently associated with asthma were discovered by the Nose and Throat Service.

The blood picture was normal except for an eosinophilia up to 6 per cent. The Kahn test was negative. Sputum was negative for tubercle bacilli on numerous occasions, but Curschmann's spirals were frequently seen. Stereoscopic x-ray films of the chest before operation revealed a moderate bilateral emphysema, but no parenchymal pathology.

A bronchoscopic examination Dec. 2, 1935, revealed no foreign body, tumor, or other mechanical obstruction.

On Dec. 4, 1935, a right dorsal sympathetic ganglionectomy was performed by the technique of Adson and Brown, removing about one inch of the fourth rib with its transverse process. The sympathetic trunk was severed above the third dorsal ganglion and below the fourth, and the intervening ganglia and sympathetic trunk were removed.

The postoperative course was uneventful and the patient was discharged eight days after operation, having experienced a few slight attacks of dyspnea which were relieved by ephedrine ¾ grain by mouth.

Attacks of asthma continued to occur on the average of about once a month. The patient, discouraged because total relief was not obtained, refused the contralateral operation until September, 1937.

On Sept. 16, 1937, a left dorsal sympathetic ganglionectomy was performed, employing the revised technique described. The pleura was accidentally torn, admitting air which was controlled with a pack until the completion of the operation and an airtight closure of the muscles without drainage could be performed.

*Microscopic Examination.*—"Section from ganglions reveal the ganglion cells to be moderately atrophic with small nuclei in which nucleoli are not visible and in which many nuclei themselves are invisible. Cytoplasm was faint-staining.

"Diagnosis: Ganglia with focal atrophy of ganglion cells." [L. C. Harris, M.D.]

The postoperative convalescence following aspiration of the pneumothorax was uneventful. The patient had two mild attacks of dyspnea which were entirely subjective, and which were promptly controlled with ephedrine, ¾ grain by mouth. No wheezing could be made out on examination but a little bronchial moisture could be heard. The patient was discharged on the twelfth postoperative day greatly improved.

The patient obtained a job as ward maid in the Baptist Memorial Hospital where she worked continuously for two years.

On June 26, 1939, a check-up examination revealed that the patient had gained 63 pounds in weight. She had had no true asthma attacks since the first month after her second-stage operation. She occasionally felt "choked up" when working in a hot and stuffy place, but these symptoms were relieved by either leaving the room or taking an ephedrine capsule. No abnormal signs could be heard on physical examination of the chest. The patient stated that she had not lost a day of work because of asthma since she obtained her job nineteen months previously.

A check-up interview in September, 1946, revealed that the patient had taken a course in nursing at Meharry University, had gained 100 pounds, and was working regularly as a registered nurse. The patient stated that she occasionally "chokes up," especially on taking cold. During these periods she receives an injection of a few minims of adrenalin or takes ⅜ grain of ephedrine by mouth as often as twice daily. Much of the time no medication is required.

Relatives report in May, 1947, that the patient is working in St. Louis and is "fat and fine and we done saved her life."

CASE 2.—E. S., a Negro woman, aged 32 years, married, entered the hospital Dec. 1, 1935, stating that she had suffered from asthmatic attacks for seventeen years. At first these attacks were seasonal, occurring particularly in the summer and fall, but since 1932 the attacks had been almost constant, especially since the removal of nasal polyps.

The past history revealed antisyphilitic treatment twelve years previously, unsuccessful attempts to treat severe pyorrhea and to control caries of the teeth, constipation, and the "whites" for many years. The patient had suffered several attacks of so-called pneumonia.

Physical examination showed an orthopneic Negro female in respiratory distress. Nasal polyps and dental caries were present. The chest was barrel-shaped and auscultation revealed the typical râles, rhonchi, and siffles of bronchial asthma. There was marked clubbing of the fingers.

The blood picture was normal except for an eosinophilia of 2 to 18 per cent. The Kahn test was negative. The sputum showed Curschmann's spirals on all examinations, and eosinophiles in some specimens. No tubercle bacilli were found. Stereoscopic x-ray films of the chest revealed a marked bilateral emphysema, thickening of the vascular lung markings, but no parenchymal disease.

Bronchoscopic examination Dec. 4, 1935, revealed the upper trachea deflected to the right, but with no marked angulation. No foreign body, tumor, or other mechanical obstruction was found. Much glarey mucous was removed by aspiration.

On Dec. 11, 1935, with 0.5 per cent procaine anesthesia, a right dorsal sympathetic ganglionectomy by the technique of Adson and Brown was performed.

The following day the patient developed a total atelectasis of the left lower lobe which was controlled with carbon-dioxide and oxygen inhalations, ammonium chloride, and postural drainage. The convalescence was otherwise uneventful and the patient was discharged on the seventeenth postoperative day having had no further attacks of asthma.

In a few weeks the patient again began having occasional attacks of asthma, but less frequently and with less severity than before the operation. On only one occasion was the

patient admitted to the hospital for medical treatment. This patient was so encouraged by the results of the first operation that she refused the contralateral operation. In January, 1936, she had an attack of lobar pneumonia in the right upper lobe, pneumococcus Type IV, which resolved by lysis. Stereoscopic x-ray films before discharge fourteen days later showed complete resolution.

The patient was persuaded to return for the contralateral operation and on Sept. 14, 1937, the left third and fourth dorsal sympathetic ganglia were resected by the revised technique.

The postoperative course was extremely smooth. The patient had a slight constant wheeze for which no medication was required. Discharge from the hospital occurred on the twelfth postoperative day.

Beginning about two weeks after her discharge from the hospital the patient began again having severe paroxysms of dyspnea which were worse than those in the interval between operations. These continued frequently and severely for another six weeks, then they began to disappear gradually. Four months after operation the patient obtained a job as house maid and worked continuously for three months. Since then she has been doing housecleaning work by the day.

At check-up examination on May 10, 1947, the patient states that she feels better than she ever has in her life. She weighs 140 pounds, an estimated gain of thirty-two pounds in the past ten years. She does day work and has lost no time in the past three years because of her health.

The patient admits that she occasionally feels an attack of asthma coming on and that her favorite treatment is to "drink a little whiskey," which usually averts the paroxysm. On two occasions, in spite of liberal self-treatment, aminophylline has been required for relief.

It is the opinion of the authors that this patient has no true asthmatic attacks, but becomes worried when the chest begins to feel tight from her residual emphysema and bronchitis.

CASE 3.—J. W., a Negro boy aged 13 years, entered the hospital Oct. 19, 1938 complaining of severe attacks of asthma for about nine years. The paroxysms were not seasonal and had been increasing in frequency and intensity until they were almost continuous. The patient had lost sixteen pounds in the previous nine months and had been completely out of school for a year.

The past history was negative except for measles, mumps, and pertussis in early childhood.

The family history revealed the patient's father and one aunt with asthma. All other close relatives were living and well.

Physical examination showed a fairly well-developed but poorly nourished Negro boy. The chest was barrel-shaped and auscultation revealed marked inspiratory and expiratory rhonchi, siffles and musical râles. Physical examination was otherwise negative.

Blood examination showed 6,000,000 red blood cells, 16 Gm. of hemoglobin and a normal total white cell count. In the differential white cell count were 2 basophiles, 34 per cent eosinophiles. The blood Kahn was negative. Sputum examinations were negative for tuberculosis, but revealed large numbers of Curschmann's spirals.

Stereoscopic x-ray films revealed congested vascular lung markings with slight emphysema in both lower lobes. No evidence of parenchymal pathology was seen.

Bronchoscopy on Oct. 20, 1938, showed the tracheal and bronchial mucosa normal, the secondary bronchi were slightly narrowed and contained much frothy mucoid exudate. No foreign bodies, tumors, or other obstructions were seen.

On Oct. 27, 1939, a left dorsal sympathetic ganglionectomy was performed, removing the third and fourth sympathetic ganglia in the manner previously described.

*Microscopic Examination.*—Sections are from ganglion. Ganglion cells reveal some autolytic changes. The interstitial cells may be slightly increased. The surrounding connective tissue is dense and fibrous in some regions.

"Diagnosis: Slight fibrosis of ganglion." [Dr. W. W. Brandes]

Convalescence from the first operation was uneventful and the patient suffered no attacks of asthma. (It is to be remembered that during the early postoperative days the patient received adequate sedation with morphine to relieve pain, which may account for the absence of paroxysms.)

On Nov. 10, 1938, two weeks after the first operation, a right dorsal sympathetic ganglionectomy was performed under ethylene anesthesia, using the revised technique.

*Microscopic Examination.*—". . . . the ganglion cells are intermingled with nerve fibers and in one portion of the ganglion there is a slight suggestion of increased cellularity. The connective tissue surounding the ganglion is slightly increased.

"Diagnosis: Nerve ganglion with mild ganglionitis." [Dr. T. M. Dunn]

The patient's immediate postoperative course was uneventful until the third day when he began to have asthmatic attacks again. These were not severe and were easily controlled with 10 minims of adrenalin. However, he continued to have one or two a day until his discharge from the hospital and repeatedly thereafter. One attack on Dec. 1, 1938, was sufficiently severe to cause his admission to the hospital, where it was controlled with aminophylline, 5 grains in 200 c.c. of 25 per cent glucose solution intravenously.

Until early May, 1939, it appeared that little benefit had been derived from the operations, as the patient continued to have frequent and rather severe attacks of asthma necessitating injections of adrenalin and aminophylline for relief. Until that time the patient missed at least two days a week from school although he was able to "carry on" during the intervals. After May 3, 1939, the patient had a perfect attendance record at school and had only rare attacks of asthma, all of which were relieved completely within fifteen minutes by an injection of adrenalin.

A reply to a questionnaire dated Jan. 11, 1947, indicates that this patient is working in a factory in Detroit as a machinist. This past fall he had some asthma between September 6 and October 30, requiring "about two shots a day." In this period the patient states he lost some time from work because of his asthma, but the rest of the year he had been able to work continuously and regularly.

In 1943 our observation of the first three patients over a period of at least four years in each case was encouraging. Each patient had some evidence of bronchial damage and pulmonary emphysema so that none were entirely symptom free. However, each was able to work and a relatively small amount of medication was required to abort asthmatic attacks when the patients believed one to be impending. These observations encouraged us to advise and apply similar operations to two additional desperate patients with intractable asthmatic symptoms.

CASE 4.—R. T., aged 59 years, a white man, entered the hospital April 28, 1943, as an emergency because of extreme dyspnea, wheezing, cyanosis, and loss of consciousness.

The history obtained later indicated that the patient could not remember when he did not have attacks of asthma to a greater or lesser degree, but that in the preceding four months following a cold they had become much more severe and almost continuous. Cough with intermittent episodes of purulent sputum had been present for several years. There had been a loss of 25 pounds of weight in the preceding four months.

The patient's attacks of dyspnea had gradually become refractory to all types of medication including adrenalin, ephedrine, aminophylline and numerous patent remedies.

Physical examination showed an emaciated elderly man, unconscious, cyanotic, with all accessory muscles of respiration intensely active. There was ptosis of the right eyelid.

Examination of the chest showed a barrel-shaped thorax with limited excursion. There was a great deal of bronchial rattling to be heard on auscultation as well as both inspiratory and expiratory sifflés and musical râles. Heart sounds were distant and the heart rhythm was irregular.

Emergency treatment consisted of a bronchoscopic aspiration of secretions, nasal oxygen, 7½ grains of aminophylline in 10 per cent glucose, and rapid digitalization.

X-ray films and bronchograms obtained later showed a very marked bilateral pulmonary emphysema and extensive cylindrical bronchiectasis. All bronchi without bronchiectasis were attenuated.

The blood examinations showed a normal red cell count and hemoglobin with a white cell count of 15,600. Eosinophiles ranged from 4 to 8 per cent but the blood picture was otherwise not remarkable. The Kahn test was negative.

During the ensuing three months the patient was never completely free from his dyspnea and wheezing which varied from day to day in severity in spite of attempts to control it with all types of standard medical therapy. The bronchial infection was controlled adequately with a postural drainage routine supplemented with expectorants and a high fluid intake.

On Aug. 6, 1943, a left dorsal sympathetic ganglionectomy was performed by the technique previously described, except that in this case the second, third, fourth, and fifth thoracic sympathetic ganglia with the intervening sympathetic trunk were excised. During the operation a small tear was made in the pleura creating a pneumothorax, but with positive pressure the lung was re-expanded as the wound was closed in layers and no respiratory embarrassment was experienced.

By Aug. 30, 1943, the patient had gained 10 pounds in weight although he still experienced occasional slight attacks of asthma which were relieved with one Tedral tablet.

On Sept. 14, 1943, the contralateral right dorsal sympathetic ganglionectomy was performed, again removing the second, third, fourth, and fifth ganglia. Convalescence from this stage was uneventful. The patient was discharged from the hospital on the twelfth postoperative day.

On Oct. 14, 1946, the patient stated that he wheezed very little but that his chest "stopped up" occasionally, requiring a bronchoscopic aspiration of his secretions. He stated that these attacks of dyspnea are never severe enough to make him sit up to get his breath.

Physical examination revealed a normal temperature, pulse rate, respiration rate, and blood pressure of 140/80. His weight was 119½ pounds. Examination of the chest showed rhonchi predominantly in the right lung. Bronchoscopic examination showed a significant amount of mucopurulent secretion in the right lower lobe bronchi but the membrane in the other bronchi appeared relatively normal.

In response to a questionnaire dated January, 1947, the patient stated that he is actively managing his farm, that he sleeps fairly well, and that his appetite is good. He tends to have some "choking spells" in the late afternoon and at night but "these attacks I have now are light and it just takes a few drops of adrenalin to stop them. I seem to be getting along fairly well."

CASE 5.—T. B., aged 29, a white married man, an engineer. The patient was first seen on May 23, 1941, complaining of asthma and a cough productive of mucopurulent sputum.

The patient stated that fifteen years previously he began having attacks of asthma which became progressively worse until they would last for days at a time regardless of medication. There was a history of mucopurulent sputum following colds for many years.

Three weeks previously the patient had had "flu" with fever to 104°F. for three days, treated with sulfathiazole. He had experienced pleurisy in the left anterior chest following the acute infection.

Physical examination revealed an asthmatic white male in moderate respiratory distress. Blood pressure was 106/68 and weight 140 pounds, representing a recent loss of 6 pounds.

Chest examination revealed many inspiratory and expiratory sibilles, râles and rhonchi bilaterally, particularly prominent in the right axilla.

X-ray film May 22, 1941, showed multiple cystic areas in the right midlung field with fibrotic infiltration extending out from the hilum into both lungs.

Bronchograms showed irregularity and slight cylindrical dilatation of the bronchi in both bases.

Bronchoscopy showed an edematous pale mucous membrane in the trachea and major bronchi with evidence of irregularity and scarring in the secondary branches.

The laboratory reported blood counts within normal limits and an eosinophilia ranging from 3 to 7 per cent. Sputum was negative for tubercle bacilli on both concentration and culture.

For two years the patient was treated with bronchial drainage routine including expectorants, tedral tablets, aminophylline, and occasional bronchoscopy. Attempts were made by competent allergists to eliminate contact with allergenic proteins to which the patient was sensitive and to desensitize him to those from which he could not be separated. For three months the patient was improved and gained 16 pounds in weight but in August, 1943, the attacks returned with renewed severity and the patient proved to be adrenalin-fast. At this time the patient was taking 12.0 c.c. of adrenalin a day without relief and he became anxious to submit to a sympathetic ganglionectomy.

On Aug. 27, 1943, a left sympathetic ganglionectomy was performed, removing the left second, third, fourth, and fifth dorsal sympathetic ganglia. Convalescence was uneventful and the patient left the hospital eight days later. For one week he had no asthmatic symptoms but at that time he caught a cold which renewed his cough, sputum, dyspnea, and wheezing.

On Oct. 8, 1943, the contralateral stage of the operation was performed, removing the right second, third, fourth, and fifth dorsal sympathetic ganglia. At this stage a tear was made in the pleura, but collapse of the lung was prevented by the application of positive pressure anesthesia and the wound was closed tightly without drainage. Convalescence was marred only by the discomfort of pleurisy, presumably due to a small amount of pneumothorax creating tension on some intrapleural adhesions. The patient left the hospital on the twelfth postoperative day with the lung well expanded.

Since operation the patient has had no severe attacks of asthmatic symptoms. It has been necessary for the patient to utilize the bronchial drainage routine from time to time to clear up the sequelae of respiratory infections.

In response to a questionnaire dated Jan. 8, 1947, the patient reported his general condition good. He stated that he has no severe attacks of asthma, but "chokes up some when I have a cold and usually tighten up a little on rising in the morning and about bedtime." He occasionally takes 0.2 c.c. of 1:1,000 adrenalin when his chest feels tight. He further declares that he had missed only a few days of work in the last two and one-half years.

Each of these last two patients has a known bronchiectasis, pulmonary emphysema, and one has actual cystic disease of the right lung. The present symptomatology is comparable to that experienced by all other patients with these irreversible changes in the bronchi and lung parenchyma.

## RESULTS

From a statistical standpoint this small group of five patients is of no consequence. To the patients concerned the operations have been extremely important since all five have been enabled to return to useful occupations. From a surgical point of view the results are interesting because these patients have obtained as complete relief as those subjected to the more extensive operation effecting complete denervation of the lung.

All five patients upon whom we operated had intractable asthmatic symptoms of long duration. It is not surprising that there should be permanent changes in the bronchial mucous membrane such as thickening, loss of ciliary action, and, in two cases, bronchiectasis. Pulmonary emphysema is, of course, present in all cases. It is interesting that the residual symptoms of each of the five patients depend largely upon the presence or absence of respiratory infection at the time. It is believed that the symptoms of "choking up" and wheezing associated with colds are due more to these permanent bronchial and parenchymal changes than to the old asthma mechanism.

All five patients have gained weight in amounts varying from 10 to 100 pounds. Only two patients report losing any time from work because of "asthma" within the past year, neither of them for more than a few days. All patients report a satisfactory response to small amounts of medication when an impending attack is feared.

It is of further interest to note that the patients whose operations have been performed the longest (ten years) have progressively shown the greatest improvement.

## SUMMARY

1. We are not prepared to say what the metabolic, biochemical, or systemic disorder underlying bronchial asthma may be, nor to propose a cure for the basic condition causing it.

2. Evidence is presented to indicate that a basic metabolic or systemic disorder producing the symptoms of asthma does exist.

3. Observations of reduction of bronchial lumina between attacks of asthma suggest that changes in the condition of the bronchial mucosa and its glands are responsible for intermittent attacks of symptoms, rather than contraction and relaxation of smooth muscle.

4. Opinions are quoted which contend that the vagus is not a simple bronchial constrictor nerve, but that the thoracic sympathetic trunks and ganglia also contain "constrictor fibers," and that their influence upon the bronchial mucosa and glands seems certain.

5. Sensitization to adrenin of structures which normally have a sympathetic nerve supply is suggested as a possible explanation for the effects of sympathetic denervation of the lungs in asthma.

6. An operation is described for the bilateral excision of the third and fourth dorsal sympathetic ganglia, and three cases of asthma so treated with beneficial results are reported. Two additional patients on whom bilateral excision of the second, third, fourth, and fifth dorsal sympathetic ganglia was performed are also described.

7. After observing the first patients for ten years and the later ones for four years, we are encouraged by the results obtained to proceed with the operation upon others whose asthma appears to be intractable.

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## DISCUSSION

DR. OSLER ABBOTT, Atlanta, Ga.—At Emory University we have also been interested in this problem but have approached it by direct attack upon the parasympathetic nervous system. During the past two years we have utilized a transpleural approach in order to resect the pulmonary components of the vagus nerve in nine patients with intrinsic bronchial asthma. It appears particularly important to isolate the vagus throughout its entire course in the posterior hilar area. The number of branches going to the lung has been many more than one would expect, and we have noted a minimum of five branches on each side. There has been one to two branches along the superior surface of the pulmonary artery, a large branch along the posterior surface of the mainstem bronchus, and one along the posterior surface of both the superior and inferior pulmonary veins. On the left side there is frequently an additional branch going along the artery and arising from the inferior surface of the recurrent laryngeal nerve. We have also stressed the ligation of each branch prior to its transsection, and conclude the operation by transplanting the entire hilar portion of the vagus nerve into the pleural cavity, by interposing the mediastinal pleura between the nerve and the distal ends of the severed pulmonary branches.

The two sides in each patient have been operated upon at a minimum of a three-month interval, in order to allow us to observe the effect upon the individual lung. The patients have uniformly remarked upon a marked increase in respiratory reserve. We have noted a constant change in physical signs, in that there is a prolongation and accentuation of the expiratory phase of respiration, almost assuming a tubular quality.

The increase in the vital capacity has been our most striking finding. Inasmuch as all patients were only subjected to this experimental procedure when they had become totally incapacitated, and all had severe associated emphysema, we have rapidly come to the preliminary conclusion that our most beneficial effect has been upon the emphysema component of the disease. So strongly have we felt this, that recently we have utilized it in cases of emphysema alone. In the group with bronchial asthma the increase in vital capacity has ranged from 88 to 128 per cent.

However, we appreciate that we are dealing with a disease containing a major psychosomatic complex, and we do not feel justified in making any final interpretation until a five- to ten-year period of observation has elapsed.

DR. RALPH ADAMS, Boston, Mass.—I wish to ask two questions of Dr. Carr.

When he did the sympathectomy, did he go prior to or peripheral to the intercostal nerve root when he removed the dorsal sympathetic ganglion?

Second, did he observe some months later, when several of his patients began to have clinical improvement in their asthma any sign of Raynaud's disease or sweating in their hands?

The operation which he described corresponds closely to the operation which is now called by some people who do the preganglionic sympathectomy, the "old-fashioned sympathetic ganglionectomy," in that it was postganglionic instead of preganglionic in respect to the intercostal nerve root.

He gave the explanation of the sensitivity to adrenin. In part, the reason that the Raynaud disease patient got worse as he characteristically did from the old operation was

shown dramatically by Norman Freeman and his colleagues to be caused by sensitization to his own adrenin, perhaps from nerve regeneration.

Possibly what was a ganglionic sympathectomy may explain the delayed appearance of beneficial results in some of Dr. Carr's cases.

We have operated upon four patients with severe pulmonary emphysema and cysts, in each of whom there was at least one cyst causing mechanical embarrassment to the patient's respiration. In each of those four cases, the cyst of greatest size was removed. The hundreds of others naturally were not attacked; the cyst wall was enfolded, and at the same time two autonomic nerve types of operation were done, one Dr. Abbott has just mentioned, removing the vagal fibers in the hope of attacking the bronchial spasm phenomena, and second, the sympathetic fibers, in the hope of recreating a sensitization to their own adrenin, if it be of practical value, as we thought it might be from theoretical considerations.

One of those patients died. The other three had greater improvement than I had any idea they would or should have had. Each of these three patients changed from invalidism to a useful but light occupation, one patient four years after operation, is just now, in the past three months, beginning to return to a status comparable to that at the time he was operated on.

Another patient was suspected of having carcinoma, but had a granuloma in his right lung. Because he had asthma, a unilateral vagal denervation was done, and I could not see that it did him any good.

One patient had a bilateral operation of the specific type that Dr. Carr described, for severe asthma, of the type that required oxygen therapy and air-conditioned rooms. Her reaction after the first side was dramatic. There was great improvement. She was anxious to have the second side done, and she improved further and went home, she claimed, a well patient. She stayed well for five weeks, and in the sixth week had a family argument and returned to the hospital in status asthmaticus. Five months later that patient had again begun to show improvement. We had our psychiatrist look into the matter, which may be the explanation.

DR. J. HUGHES CHANDLER, Jackson, Tenn.—The type of resection done was postganglionic, and in none of these resections was there noted any evidence of Raynaud's disease postoperatively.

We were especially interested in a comparison of results between the dorsal sympathectomy as it was done to include stellate ganglia and those of the type which we have done. We have purposely excluded stellate ganglia because of the unpleasant symptoms that would have been produced by Horner's syndrome.

I would like to further emphasize that denervation operations will afford no benefit to patients whose bronchial tree has become rigidly constricted by chronic fibrosis, or in advanced emphysema.

DR. DUANE CARR, Memphis, Tenn.—Frankly, we now feel we know nothing for sure about asthma. Ten years ago when this work was started we felt confident in our knowledge, but conflicting opinions in the literature and observed physiological results which cannot be reconciled with them leave us feeling ignorant. We hope that this will result in our learning something more definite.

It is high time we held up some of the old ideas which have been taken for granted to close scrutiny. I feel right now that, as Dr. Grace has said, the entire physiology of asthma needs to be reviewed.

As for the relative merits of the dorsal sympathectomy, dorsal sympathetic ganglionectomy, and the posterior pulmonary plexus neurectomy, we have no opinion. We were trying to get away from an extensive transpleural operation. Our patients were so desperately ill that they could hardly have tolerated a major procedure of that type.

If the simple resection of the dorsal sympathetic ganglia will serve the purpose, and after watching some of these patients for ten years, we believe it has; we believe that the amount of surgery or surgical trauma necessary to bring relief has been greatly minimized.

# ARTERIOVENOUS FISTULA OF THE LUNG

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THE development of large, vascular channels between a pulmonary artery and vein results in a characteristic clinical syndrome which is being recognized with increasing frequency.[1, 4, 5, 7, 10-16] We are herewith reporting a study of the circulatory dynamics in pulmonary arteriovenous fistula. The disturbances in circulation associated with an arteriovenous fistula in a large peripheral vessel have been the subject of intensive investigation.[9] The data reveal points of contrast between the alteration in circulatory dynamics produced by arteriovenous fistula in the lesser as compared with the greater circulation. Included in this paper is a case report of a pulmonary arteriovenous fistula with superimposed bacterial endarteritis, which was successfully treated by chemotherapy and lobectomy. To our knowledge this is the first case of bacterial endarteritis superimposed on a pulmonary arteriovenous fistula that has been observed.

An arteriovenous fistula not caused by trauma, infection, or degenerative changes in the walls of blood vessels is a form of cavernous hemangioma. The size of the vascular channels in hemangiomas varies considerably. When large arteries and veins are present, a free communication between the arterial and venous system may be established. A cavernous hemangioma of the lung may result in the shunting of a considerable amount of venous blood from the pulmonary artery to the pulmonary vein and left auricle. The blood passing through the shunt does not go through the capillaries of the lung and thus fails to be oxygenated in the normal manner. Since the lung has a dual blood supply from the pulmonary and bronchial systems, one or more tributaries of both systems may communicate with the cavernous hemangioma. The part played by each vascular system varies in different cases. Those patients who show marked cyanosis, clubbing of the fingers, and polycythemia undoubtedly have a large fistulous communication between the pulmonary artery and vein. In the absence of cyanosis and polycythemia, cavernous hemangioma of the lung may be suggested on physical examination by the presence of a loud murmur over a portion of the lung. Perhaps in the latter instance the bronchial arteries play a more prominent role in supplying blood to the cavernous hemangioma. If this hypothesis is correct, the pressure within such a cavernous hemangioma might be greater and the risk of hemoptyses increased.

Heredity seems to play a role in the occurrence of arteriovenous fistula of the lung. Goldman[5] has reported hemangioma in the lungs of two brothers.

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Whitaker[16] reported a case of pulmonary arteriovenous fistula with a family history of telangiectases. One of our patients gave a history of multiple telangiectases in three generations.

The symptoms in arteriovenous fistula of the lung tend to vary, depending partly on the degree of polycythemia. The patient may be asymptomatic, but in most of the cases reported symptoms have been noted. Cough is only an occasional complaint. Dyspnea on exertion is often present, particularly if the arteriovenous shunt is large. Hemoptysis may occur and sometimes the bleeding is severe and may even be fatal.[2] There are usually no symptoms of pulmonary infection, but one of our patients developed septicemia due to bacterial endarteritis occurring in the arteriovenous fistula. Headache occurs in patients with marked polycythemia and one patient had epileptiform seizures.[14] Epistaxis is not infrequent.

The physical findings in arteriovenous fistula of the lung may vary. Approximately one-half of the patients have hemangiomas elsewhere, particularly around the head. Telangiectasia of the lips is common. Polycythemia and clubbing of the fingers and toes are present in those patients with cyanosis. There is often a history of cyanosis dating from early life, and in some cases this was noted shortly after birth. The cyanosis tends to become worse as the patient grows older. The cardiac findings are normal. The heart is not enlarged. In about half of the cases a murmur may be heard over the portion of the lung field where the arteriovenous fistula is located. The murmur tends to be louder during inspiration, and may be almost continuous in character, often with systolic accentuation. The roentgen findings are rather characteristic. One or more areas of density in the lung field may be noted. The shadow may be somewhat rounded, but often has an irregular border and sometimes the margin is wormlike. Pulsation may be noted on fluoroscopy. The density is usually continuous with the vascular markings, and the vessels leading to it are usually enlarged. Stereoscopic views and planograms may demonstrate the connection with the pulmonary vascular tree to better advantage. Angiocardiograms confirm the diagnosis (Fig. 1). It would seem advisable to perform angiocardiography in every case of arteriovenous fistula of the lung prior to operation, since by this method multiple arteriovenous fistulae which are not obvious on a routine roentgenogram may be demonstrated. In approximately one-half of the reported cases, multiple lesions in the lung have been found. Lesions occurring at the pulmonary bases may be obscured by the cupula of the diaphragm and those in the medial portion of the left base may be obscured by the cardiac shadow.

The laboratory findings in cavernous hemangioma of the lung are dependent upon the size of the shunt from pulmonary artery to pulmonary vein. The red blood cell count may be as high as eleven million, and a hemoglobin as high as 23.7 Gm. has been reported.[15] In one case the hematocrit was 80 per cent. The blood count may be normal if there is no significant shunt between the pulmonary artery and vein. An arterial oxygen saturation at rest as low as 70 per cent has been recorded. In one of our patients the resting arterial oxygen saturation was 74 per cent, but on exercise it dropped to 59 per cent.

Cavernous hemangioma of the lung with polycythemia must be differentiated from other lesions which produce an abnormally high erythrocyte count. In the past, diagnoses of polycythemia vera have been erroneously made. The absence of splenic enlargement should aid in differentiation. Hirsch[8] has reported pulmonary lesions in polycythemia vera which were probably caused by intravascular thrombosis. These lesions can be differentiated from pulmonary arteriovenous fistulae by their changing character on serial films and their tendency to clear. The absence of any clinical or roentgen evidence of cardiac abnormalities should differentiate pulmonary cavernous hemangiomas from congenital cardiac lesions. Polycythemia due to diffuse pulmonary disease and chemicals must be ruled out.

Fig. 1.—Angiocardiogram shows large arteriovenous aneurysm in right lung outlined by diodrast. Note the large pulmonary vein leading from the vascular mass. (Courtesy of Dr. M. Sussman.)

Cases of cavernous hemangioma without polycythemia and cyanosis may be suspected on the basis of a murmur heard over the involved portion of the lung. If no murmur is audible, it may not be possible to establish the diagnosis by the roentgen appearance alone unless the contour of the shadow strongly suggests a vessel. In such cases, angiocardiography will be conclusive. Murmurs may also be produced by arteriovenous fistulae in the chest wall.

Malignant hemangiomas may occur in the lung as elsewhere.[3, 6, 17] They are very rare and do not produce the signs of pulmonary arteriovenous fistulae. The tumor, however, may be very vascular. Usually the metastases are widespread.

The chief and most common complications of arteriovenous fistula of the lung are those associated with polycythemia. Hemoptysis has occurred in the minority of cases, but is a potential hazard because of the severity of the bleeding which may occur. The possibility of bacterial endarteritis exists in any case of arteriovenous fistula, irrespective of its location.

The treatment of pulmonary arteriovenous fistula is surgical excision. Since the lesions may be multiple, and because of the possibility of additional arteriovenous fistulae becoming manifest later, conservation of pulmonary tissue is indicated. Local or segmental resection of the lung is feasible in some cases. Usually either lobectomy or pneumonectomy has been required, depending upon the size and location of the vascular channels. Because of the possibility of associated vascular anomalies, one should be certain that adequate channels for the return of blood to the left heart remain. In the case reported by Jones and Thompson,[12] a single pulmonary vein was present. Had this not been recognized and only a lobectomy performed, the returning blood flow from the remaining portion of the lung would have been obstructed.

In two cases of arteriovenous fistula of the lung reported in the literature, an attempt was made to lessen the blood flow through the shunt by the induction of a pneumothorax.[7, 12] A good collapse of the lung was obtained in both instances, but after several months of pneumothorax there was no appreciable change in the degree of polycythemia. The results indicate that collapse of the lung causes little change in the amount of blood passing through the arteriovenous fistula.

## CASE REPORT

M. F., a 20-year-old woman, stated that her fingernails and lips had been blue as long as she could remember. Her mother was uncertain as to whether she had been "blue" at birth, but had noticed increasing cyanosis since infancy. Clubbing of the fingers had been present for many years. She tired easily on exertion and showed some dyspnea. These symptoms had become more marked in the past few years. In 1941 a chest roentgenogram had revealed an area of density in the right lower lobe (Fig. 2), but the nature of the lesion was not recognized. Epistaxis had occurred frequently since 1944. In February, 1944, an abscess appeared in the right ankle region. This healed slowly after drainage. In the early part of 1946 an abscess developed over the heel on the same side. It was incised and pus containing nonhemolytic streptococci was obtained. Drainage had continued for four weeks when the patient suddenly became acutely ill with a high fever. On admission to the hospital, in March, 1946, a roentgenogram of the chest showed a defect in the sixth rib on the left side and a diagnosis of osteomyelitis of the rib was made. The chest roentgenogram (Fig. 3) also showed a dense area at the right base which was considerably larger than that seen on the x-ray film taken five years previously. While in the hospital the patient ran a febrile course and a blood culture taken on admission was positive for nonhemolytic streptococci. A left-sided empyema due to the same organism developed, and was treated by intrapleural instillations of penicillin combined with large doses by intramuscular injection. Sulfadiazine was given by mouth.

Physical examination revealed cyanosis of the mucous membranes, fingers, and toes. Clubbing of the fingers and toes was marked. Acne vulgaris of the face, chest, and back was present. There was marked myopia and internal strabismus. The thyroid was slightly enlarged. Heart sounds were normal; no murmurs were present. The blood pressure was 100/70 mm. Hg. An electrocardiogram was normal. At the base of the right lung posteriorly a continuous murmur could be heard over an area several centimeters in diameter. The murmur was louder during inspiration and there was slight systolic accentuation. The area of

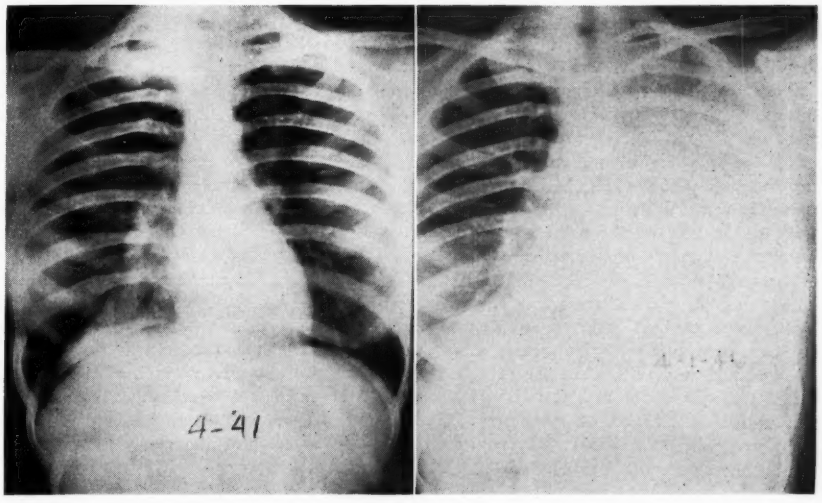
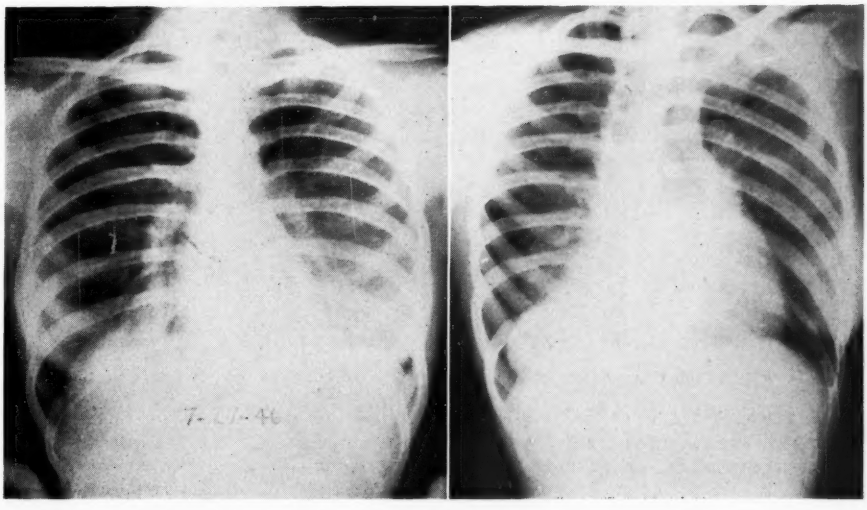



Fig. 2. Fig. 3.

Fig. 2.—Roentgenogram in 1941 showed an area of density in the right lower lobe.

Fig. 3.—Roentgenogram in 1946 showed density over the left hemithorax due to empyema. A defect in the left sixth rib, due to osteomyelitis, is present. The area of density at the right base, which is the arteriovenous fistula, has enlarged considerably in the five-year interval.



*A.* *B.*

Fig. 4.—*A*, Roentgenogram of chest taken before operation for arteriovenous fistula. The left sided empyema has cleared. *B*, Oblique view shows aneurysmal sac above diaphragm.

the murmur corresponded with the location of the density seen in the right lung field on the roentgenogram. A diagnosis of bacterial endarteritis occurring in an arteriovenous fistula of the right lower lobe of the lung was made. Because of the presence of the left-sided empyema, no surgical intervention for the arteriovenous fistula in the right lung was feasible at this time. Over 12 million units of penicillin were given during a four-week period. Sulfadiazine was continued for many weeks and the temperature gradually approached normal. The osteomyelitis of the rib and the empyema subsided. The blood cultures remained negative after the first few weeks of illness. Excision of the arteriovenous fistula of the right lung was delayed until the pleuritic reaction on the left side had thoroughly subsided (Fig. 4). During the interim a maintenance dose of one gram of sulfadiazine daily was given. Several months after the septicemia had cleared, the bruit at the base of the right lung was heard only with difficulty. Angiocardiogram confirmed the diagnosis of pulmonary arteriovenous fistula (Fig. 1). At operation on Nov. 20, 1946, a right lower lobe lobectomy with excision of the arteriovenous fistula was performed. Because of the patient's marked polycythemia, infusion was given prior to operation to lessen the hazard of intravascular thrombosis. Only blood plasma was given during the operative procedure. The pulmonary artery to the lower lobe was found to be tremendously enlarged and very thin, while the vein from the lower lobe appeared normal. This thinning out of the wall of the artery, which is also present in peripheral arteriovenous fistulae, has been called venafication of the artery. The aneurysmal sac was densely adherent to the diaphragm, due to a chronic inflammatory reaction. The color of the patient improved as soon as the artery was ligated.

Fig. 5.—Photograph of specimen showing aneurysmal sac of arteriovenous fistula of the lung.

The excised lobe of the lung revealed a large, thin-walled pulmonary artery which entered a large sac with some recesses. Another opening in the thin-walled sac led to the pulmonary vein. On a ridge on the inner aspect there was a thickened area which probably represented the site of previous vegetations. It required 150 c.c. of solution to distend the vascular channels of the cavernous hemangioma. The sac alone had an 80 c.c. volume (Fig. 5).

The postoperative course was essentially uneventful. The right upper and middle lobe expanded well (Fig. 6). The postoperative drop in red blood cell count and hematocrit was more pronounced than could be accounted for by the estimated blood loss at the time of operation.

Studies of the respiratory and circulatory function were done before operation and on four occasions during the ensuing six months (Charts I, II, III). Before operation the lung volumes were normal (Chart I), but the oxyhemoglobin saturation of the arterial blood was 74 per cent at rest and dropped to 59 per cent after the standard exercise test (Chart II). The oxygen content of the arterial blood was 20.6 volumes per cent and of the mixed venous 16.4 volumes per cent. Cardiac catheterization studies revealed a normal cardiac output and normal pressure relationships in the right auricle, right ventricle, and pulmonary artery (Chart III and Fig. 7). The shunt through the arteriovenous aneurysm was estimated to be 58 per cent of the total blood flow at rest. Plasma volume was normal and total blood volume was increased due solely to the large volume of red cells; the hematocrit was 70 per cent.

CHART I. OBSERVATIONS ON THE LUNG VOLUMES, THE MAXIMUM BREATHING CAPACITY, AND THE SEPARATE FUNCTIONS OF THE RIGHT LUNG IN A CASE OF PULMONARY ARTERIOVENOUS FISTULA

| M.F. 20 YEARS | PREDICTED | BEFORE OPERATION | FIVE MONTHS AFTER OPERATION |
|---|---|---|---|
| Vital capacity (liters) | 3.0 | 3.3 | 2.3 |
| $\frac{\text{Residual air}}{\text{Total lung volume}} \times 100$ | 26 | 26 | 34 |
| Maximum breathing capacity (liters per minute) | 96 | 74 | 81 |
| Bronchospirometry (percentage of total function on the right side) | | | |
| Vital capacity | 53 | 57 | 38 |
| Ventilation | 53 | 49 | 49 |
| Oxygen intake | 53 | 42 | 25 |

CHART II. OBSERVATIONS ON THE BLOOD VOLUMES AND OXYGEN TRANSPORT IN A CASE OF PULMONARY ARTERIOVENOUS FISTULA

| M.F. 20 YEARS | NORMAL | BEFORE OPERATION | SIX MONTHS AFTER OPERATION |
|---|---|---|---|
| Blood volumes (c.c./Sq.M.B.S.A.)* | | | |
| Total volume | 2,700 | 4,800 | 2,170 |
| Plasma volume | 1,600 | 1,460 | 1,350 |
| Red cell volume | 1,100 | 3,340 | 820 |
| Hematocrit (%) | 40 | 70 | 36 |
| Red cell count (million) | 5.0 | 6.9 | 4.4 |
| Hemoglobin (Gm.) | 14.5 | 22 | 13 |
| Oxyhemoglobin saturation (%) | | | |
| At rest | 96 | 74 | 96 |
| After exercise | 96 | 59 | 90 |

*c.c./Sq.M.B.S.A. = Cubic centimeters per square meter of body surface area.

CHART III. BLOOD PRESSURES IN THE RIGHT HEART AND PULMONARY ARTERY, AND CARDIAC OUTPUT* IN A CASE OF PULMONARY ARTERIOVENOUS FISTULA

| M.F. 20 YEARS | PRESSURES (MM.HG) | | |
|---|---|---|---|
| | SYSTOLIC | DIASTOLIC | MEAN |
| Brachial artery | 97 | 59 | 78 |
| Pulmonary artery | 17 | 8 | 12 |
| Right ventricle | 17 | 4 | -- |
| Right auricle | -- | -- | 3 |

*Systemic blood flow (Cardiac Output) = 3.24 L./Sq.M.B.S.A./min. Arteriovenous shunt = 58 per cent of total pulmonary blood flow.

After lobectomy the blood volume and hematocrit returned to normal within four days. The oxyhemoglobin saturation of the arterial blood likewise returned to normal at rest but showed a small drop to 90 per cent after the standard exercise. The tendency for the arterial oxyhemoglobin saturation to be slightly low during exercise has persisted but has not increased, and it has been shown not to be due to a low partial pressure of oxygen in the alveolar air. The evidence suggests that during exercise a small proportion of venous blood fails to become oxygenated in the lungs. Whatever the nature of this shuntlike mechanism, it is so small as to be of no functional importance.

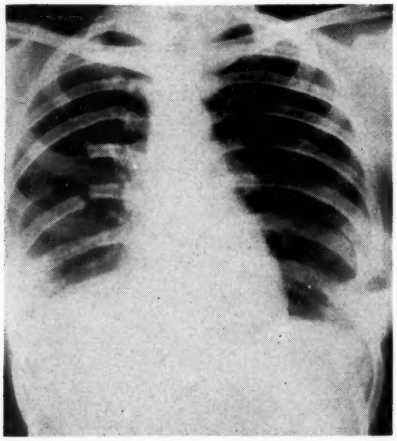


Fig. 6.—Postoperative roentgenogram shows good expansion of the right upper and middle lobes following lower lobe lobectomy.

An interesting finding during the postoperative period was a high partial pressure of carbon dioxide in the arterial blood. This was still present after two weeks but had returned to normal four months later. Preoperatively the partial pressure of carbon dioxide in the arterial blood was somewhat elevated because of the admixture of venous blood by way of the pulmonary shunt. After operation the maintenance of a high arterial carbon-dioxide pressure can have resulted only from a high alveolar carbon dioxide, due in turn to hypoventilation. This finding is probably a manifestation of the effect upon the respiratory center of the change in acid-base relationships occurring after closure of the pulmonary arteriovenous shunt. No such change occurs in a peripheral arteriovenous shunt.

A comparison of the physiological effects of peripheral and pulmonary arteriovenous fistula is of interest (see Chart IV). According to Holman,[9] an arteriovenous fistula between an artery and vein in the greater circulation results in an increase in the blood volume. The plasma and red cell volume are both increased proportionately so that the hematocrit remains essentially normal. In pulmonary arteriovenous fistula, however, the increase in blood volume is due solely to the increase in red cell mass while the plasma volume remains normal. The cardiac output is markedly increased in the presence of a large peripheral arteriovenous fistula, whereas we found a normal value in the one case of large pulmonary arteriovenous fistula in which the cardiac output was determined. Cardiac enlargement, mainly due to dilatation, is an

important finding in large peripheral arteriovenous fistula. No enlargement of the heart has been observed in the reported cases of pulmonary cavernous hemangioma, and this may be related to the normal pressures in the right ventricle and pulmonary artery and normal cardiac output found in the case studied by cardiac catheterization. Following elimination of a long-standing peripheral arteriovenous fistula with a proved increase in blood volume, there occurs a temporary concentration of hemoglobin and an increase in red cells per cubic millimeter of blood. A drop in the hematocrit and erythrocyte count occurs after elimination of a pulmonary shunt.

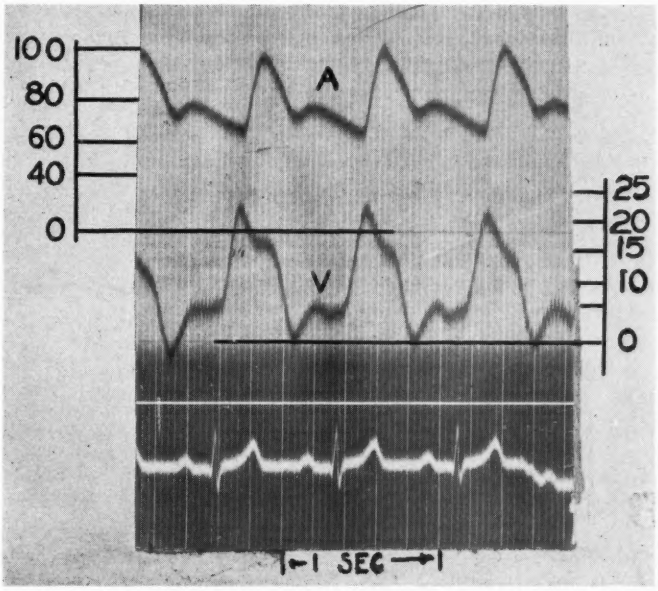



Fig. 7.—Tracings of the pressure in the brachial artery and right ventricle. All pressures in mm. Hg.

*A* = Pressure as recorded from brachial artery (scale to left).
*V* = Pressure as recorded from right ventricle (scale to right).
*ECG* = Normal Lead II.

CHART IV. PHYSIOLOGICAL EFFECTS ON THE CIRCULATION; CONTRAST BETWEEN LARGE SYSTEMIC AND LARGE PULMONARY ARTERIOVENOUS FISTULA

| | ARTERIOVENOUS FISTULA | |
|---|---|---|
| | SYSTEMIC | PULMONARY |
| Total blood volume | Increased | Increased |
| Total plasma volume | Increased | Normal |
| Hematocrit | Normal | Increased |
| Oxyhemoglobin saturation | Normal | Decreased |
| Cardiac output | Increased | Normal* |
| Cardiac enlargement | Present | Absent |

*One determination.

SUMMARY

Cavernous hemangioma of the lung may result in a pulmonary arteriovenous fistula with the development of cyanosis, polycythemia, and clubbing of the extremities, but these signs are absent in those pulmonary hemangiomas which do not result in a significant degree of shunt between the pulmonary artery and vein.

A case of arteriovenous fistula of the lung with superimposed bacterial endarteritis successfully treated with parenteral penicillin followed by surgical removal of the involved portion of lung is reported.

A summary of the preoperative and postoperative study of the cardiocirculatory and pulmonary function, including information obtained by cardiac catheterization, is presented.

The physiological alterations produced by an arteriovenous fistula in the peripheral and pulmonary circulation are compared. A peripheral arteriovenous fistula increases all elements of the blood volume proportionately, increases cardiac output, and causes dilatation of the heart. In contrast, a pulmonary arteriovenous fistula increases only the red cell mass, and has little or no effect on cardiac output and cardiac dynamics.

The authors wish to acknowledge their indebtedness to Dr. André Cournand for his guidance and advice.

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DISCUSSION

DR. RICHARD H. SWEET, Boston, Mass.—We are indebted to Dr. Maier for his singularly lucid presentation of this interesting subject, and particularly for his very adequate physiologic studies which explain the mechanism of some of the interesting findings.

Its relative rarity in our cumulative experiences is such that some slides of two such patients out of three whom I have seen in the last two years might be of interest.

(Slide.) This is a young woman of 23 years, who suffered very few physical limitations. Her only complaint was that she disliked being about, among people. Her reasons for having something done were largely social.

(Slide.) This slide is not entirely satisfactory, but it does show that the middle lobe, held by the assistant's hands, looks as thought it has a hemangiomanous lesion in it. There is one tie on an enormous pulmonary artery and another on a very large pulmonary vein.

(Slide.) This shows a specimen which indicates that there was this large vascular lake in the middle lobe, which was the location of the lesion.

(Slide.) This slide shows the young woman several months later, and it is obvious that cyanosis and clubbing have almost disappeared.

(Slide.) This is a little child who was cyanosed from birth. In fact, we have x-rays of this patient at the age of one week which show the same findings we see in the next slide.

(Slide.) This large area in the right lung field shows also that this lesion is in the middle lobe. This seems to be the characteristic location.

(Slide.) The specimen was purposely filled with blood by tying the veins before the artery, and you see these large vascular areas.

(Slide.) This slide shows the child a few weeks following the operation, and he, likewise, apparently has very few symptoms. Even before operation he was a pretty normal youngster.

I have seen a third patient—upon whom I intend to operate—who also has a lesion in the middle lung field. The third patient, however, does not have cyanosis, and I would like very much to have Dr. Maier comment on the type of case where there is no cyanosis present.

DR. PAUL C. SAMSON, Oakland, Calif.—I wish to present briefly the history of a 25-year-old man who recently underwent exploration for an unidentified infiltrative lesion of the right middle lobe. At operation, an arteriovenous fistula occupying most of the middle lobe was diagnosed. The anomalous artery was a branch of the upper lobar artery and entered the middle lobe through an incomplete fissure between the upper and middle lobes. Lobectomy was performed without incident.

A pulmonary shadow was found by a routine roentgen survey and the fistula was not suspected prior to operation. There were no localizing physical signs in the lung, and the patient did not have clubbing of the fingers. His hemoglobin was 18 Gm. (115 per cent) and the red blood count was 5,810,000. Of particular interest was the patient's "asthmatic" history which was, in large measure, responsible for our not suspecting an arteriovenous fistula. The patient was supposed to have had seasonal asthma for the past nine years and there was an indirect report that fluoroscopy of the chest some four years ago had been negative. This report has not been confirmed. The patient had an allergic attack considerably more marked than usual in February, six weeks before operation. He was admitted to the hospital in a semiconscious condition with severe cyanosis and marked expiratory dyspnea. At that time there were numerous musical râles and rhonchi throughout both lungs. This attack apparently responded to adrenalin, aminophyllin, and bronchoscopy. It will be very interesting to follow this patient and determine whether the "asthma" may not be improved or even cured by the removal of the arteriovenous fistula.

DR. LAWRENCE M. SHEFTS, San Antonio, Texas.—There are two points of interest in relation to this type of case that will bear discussion. One is the familial tendency and the other is the readiness with which phlebothrombosis occurs in these patients because of extremely high specific gravity of the blood.

With these points in mind, I would like to present a case of a patient seen at Brooke General Hospital, San Antonio. The patient to be presented is one of a family of seven,

all of whom, mother, father, daughter and four sons, presented evidence of telangiectasia and hemangioma of the skin and mucous membrane. Two of the family presented evidence of arteriovenous fistula of the lung.

The father of this patient had such hemangiomas of the lips that he could not go out in the sunlight or he would bleed from them. This is a very common story, as such patients are very sensitive to the sun. He finally had to take a job as a night watchman. He eventually died from a pulmonary embolism from phlebothrombosis of the lower extremities. He was known to be moderately cyanotic and probably had a marked polycythemia with a high specific gravity of the blood.

(Slides.) These are kodachrome lantern slides of the mother and sister. Telangiectasia can be seen on the chests.

(Slide.) The next is a kodachrome lantern slide of a brother and, though they do not show up too well here, he has small hemangiomas on his face and on his lips.

(Slide.) This is another brother; the hemangiomas on his lips can be seen more readily.

(Slide.) On kodachrome lantern slide of the third brother the hemangiomas are readily visible. The next lantern slide will show an x-ray on this particular brother.

(Slide.) In the left lower lung field is an area of opacity which I am sure is an arteriovenous fistula.

(Slide.) This is a lateral x-ray which shows this area of opacity in the lingula. Angiocardiography revealed that this was definitely an arteriovenous fistula.

(Slide.) This is a kodachrome lantern slide of the patient. It is readily visible that he had a marked cyanosis with similar areas of telangiectasia and numerous hemangiomas as were seen in the slides of his brothers. He had a polycythemia of 8,992,000; hemoglobin of 125 per cent; blood specific gravity of 1.068. He had had a previous history of thrombosis of the veins of his leg. Plasma specific gravity was 1.028; plasma protein 7.82; hematocrit 58 per cent; blood oxygen saturation: blood hemoglobin, 22.7 Gm. per 100 c.c.; femoral artery, 19.05 volumes per cent of oxygen; venous blood, 11.09 volumes per cent oxygen. Therefore, the per cent of saturation of arterial blood was 63 per cent and venous blood was 40 per cent saturation.

(Slide.) This x-ray reveals the mass to be in the right hilar region and the next slide, revealing a lateral view, shows it to be in the posterolateral portion of the right lower lobe.

(Slide.) This is an x-ray of an angiocardiography that was done, and, although it is not as clearly defined as the excellent one Dr. Maier showed, you can see that it is the same density as the heart.

(Slide.) This kodachrome lantern slide is taken during the operation after mobilization of the right lower lobe. It shows a large fist-sized mass in the posterolateral portion of the right lower lobe.

(Slide.) Another kodachrome lantern slide taken during operation after a similar mass was freed from the subclavian vessels shows another arteriovenous fistula in the apex of the right upper lobe. Scattered throughout the right middle and the lower portion of the right upper lobes were numerous ½ to 1 cm. large, bluish-black hemangiomas, and, although these did not pulsate as the larger one in the lower lobe and the one in the apex, it was felt that these, too, were arteriovenous fistulas. There were seven of these altogether and it was then decided that a total pneumonectomy rather than a lobectomy with numerous segmental resections would be done.

(Slide.) This is a kodachrome lantern slide taken of the patient's face the moment after the pulmonary artery was tied. The immediate change in color is obvious.

(Slide.) This is a picture of the patient one week postoperatively with no cyanosis.

(Slide.) The clubbing of his fingers has remained.

He developed postoperatively a thrombophlebitis in spite of the fact that he received no whole blood during operation. Only plasma was given in an attempt to reduce the specific gravity of his blood. I did not feel it safe to rely only on anticoagulants with a patient who had only one lung and, therefore, very promptly tied off both of his superficial femoral veins.

This case, I believe, demonstrates clearly the remarkable familial tendency of this disease and also the complications of handling such a patient with a high specific gravity of blood.

DR. FRANCIS R. X. BYRON, Ann Arbor, Mich.—I would like to present a case that has been encountered within the last fifteen months, because it illustrates something which has not been brought out in previous discussion.

(Slide.) This patient was 27 years of age, and had been cyanotic since birth. Her red count was 8½ million.

(Slide.) This shows the lateral chest x-ray, demonstrating the pulmonary opacity. It was thought to be in the middle lobe, but at operation it was found to be in the anterior surface of the lower lobe.

(Slide.) The probe to your left is through the pulmonary artery, the lower end of that probe, emerging through the inferior pulmonary vein, demonstrates a direct shunt from the artery to the vein. There was no murmur, and no thrill on palpitation.

The thing this patient illustrates is that the cyanosis may not immediately disappear. We were very disappointed because she continued to be somewhat cyanotic, and to have an elevated red count. We felt that perhaps we had missed another arteriovenous shunt elsewhere, but we have followed her for about fourteen months and we have found that each time she appears at the hospital, there is a decrease in her red count. One should not be disappointed if there is not an immediate fall in the red count or rapid disappearance of cyanosis.

DR. DEWEY BISGARD, Omaha, Neb.—It is becoming increasingly apparent that this lesion is not as rare as we once thought. It was first reported in 1942, and well over twenty cases have accumulated in the last five years. It was probably misdiagnosed and not recognized in the past.

I have one case to go over briefly. This man was 29 years old. He had increasing cyanosis following an upper respiratory infection eight years previously, and for three years he had dyspnea, asthmatic sort of attacks, and brief periods of loss of consciousness. For three months he had not been able to work because of the dyspnea.

(Slide.) On physical examination, he had hemangiomas of the lips, and moderate cyanosis with slight clubbing of the fingers and toes. A continuous murmur could be heard over the right lower lobe where you see this lesion in the lung field, and this murmur was accentuated on inspiration and diminished on expiration. It was heard over the eighth rib, posteriorly. I think you can see two branches leading off medially from this lesion. This is characteristic.

(Slide.) I did a right lower lobectomy and this is the film of the injected specimen. One pipette is in the artery and one in the vein. The artery was injected with barium and the film shows the filled hemangioma.

(Slide.) This is the man before operation, and I think you can see the hemangiomas of the lip, some clubbing, and moderate cyanosis.

(Slide.) Following operation, there was prompt clearing of the cyanosis. A moderate preoperative polycythemia and polyemia, also receded rather quickly.

(Slide.) This is the same patient, two weeks postoperatively.

DR. OSLER ABBOTT, Atlanta, Ga.—I wish to present, very briefly, a different type of an arteriovenous communication in the lung, in which we apparently carried out an incorrect plan of attack.

This was in the case of a child 14 years of age, who was admitted with a fairly typical syndrome of tetralogy of Fallot. He had the additional finding of a venous hum over the upper left chest. Preoperatively, the question of pulmonary arteriovenous fistula or inadequate persistent ductus arteriosus was considered.

At the first operation, done through the left side because of a right-sided aortic arch, we encountered an abnormal, large vein traveling from the superior vena cava to the first division of the left pulmonary artery, and at this point an aneurysmal area was found.

Considerable time was lost in study, dissection, and evaluation of the hydrostatic pressure on each side of the fistula. The pressure differences were not striking, but we removed the abnormal vessel and the aneurysmal communication, and repaired the left pulmonary artery. This appeared to be sufficient surgery at this time so that the second stage was carried out two months later. It was interesting to note that during the interval his cardiovascular function was definitely not improved, and the hematocrit had risen seven points. We now are of the opinion that the blood had originally been flowing from the vena cava into the pulmonary arterial system, and was probably proving to be of partial benefit to the patient. I feel, therefore, that if this anomaly is again encountered that it is much more important to treat the underlying tetralogy than the associated arteriovenous fistula.

DR. HERBERT C. MAIER, New York, N. Y.—I assume that in those cases of arteriovenous fistula with absence of cyanosis, the shunt is largely concerned with the bronchial vascular system. Such patients may have a louder murmur than some with a large shunt between the pulmonary artery and vein. However, actual proof of that hypothesis is not available at this time, and I feel that it would be desirable if these lungs would be thoroughly studied from the standpoint of the bronchial arterial system as well as the pulmonary system by injecting the vascular tree of the surgical specimen.

In the case which I presented there was considerable blood loss at operation, due to the inflammatory reaction where the aneurysmal sac was adherent to the diaphragm. But even allowing for that blood loss, we feel that the drop in the hematocrit from 70 to 34 in a few days cannot easily be explained on that basis alone.

# SURGICAL TREATMENT OF THE SOLITARY LUNG METASTASIS

DONALD B. EFFLER, M.D., AND BRIAN BLADES, M.D.
WASHINGTON, D. C.

THE ideal treatment of malignant disease is adequate surgical excision before the appearance of extension or metastasis. Since lung tissue is one of the more common sites of metastasis, radiologic examination of the thorax is one of the essential examinations of a cancer patient. Too frequently surgical intervention is abandoned on the premise that the presence of a pulmonary metastasis renders the prognosis hopeless. There is evidence at the present time to indicate that this conclusion is not always justifiable. It now appears likely that tumors have been removed in which there was evidence of a solitary lung metastasis and a cure was effected. The pulmonary lesion may have been present before initial surgery or detected at a much later date. Subsequent excision of the secondary lung tumor in a few of these patients has yielded promising results.

The term "solitary metastasis" is used in the broad sense. Actually, it is intended to mean that only one metastasis could be demonstrated at the time that excisional surgery was contemplated. Undiscovered and asymptomatic lesions may be present and assert themselves later.

## REVIEW OF LITERATURE

A review of the literature to date reveals little information on the subject of surgery for the solitary lung metastasis. Due to the paucity of reported cases it must be assumed that there have been very few successful attempts to extirpate both a primary malignant tumor and associated solitary lung metastasis.

The outstanding case report of its kind is that submitted by Barney and Churchill in 1938 and again in 1944. This patient was subjected to operation in April, 1932, for an adenocarcinoma of the kidney. One year before operation a nodule in the left lung was detected by roentgenogram, and observation revealed a gradual increase in its size. X-ray therapy was employed following nephrectomy in an effort to obliterate the pulmonary lesion, but without apparent change. On July 18, 1933, thoracotomy was performed by Dr. E. D. Churchill, and approximately two-thirds of the left upper lobe was removed. The patient made an uneventful recovery from this procedure, and has been reported as alive and well thirteen years later. In 1943, Brezina and Lindskog reported a successful pneumonectomy in a 65-year-old woman, who is believed to have had a metastasis from an adenocarcinoma of the uterus. This case is of particular interest since the patient had been subjected to a hysterectomy thirteen years earlier. At the time of her first operation, the gross diagnosis of uterine carcinoma was offered, although no microscopic studies were made. The removed lung showed a solitary metastasis of uterine adenocarcinoma. In 1941, Raine

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Fig. 1.—Case 1. Reproduction of specimen following supracondylar amputation of right leg. The normal soft tissue of the posterior leg has been dissected away, exposing the primary tumor mass which is identified microscopically as malignant synovioma.

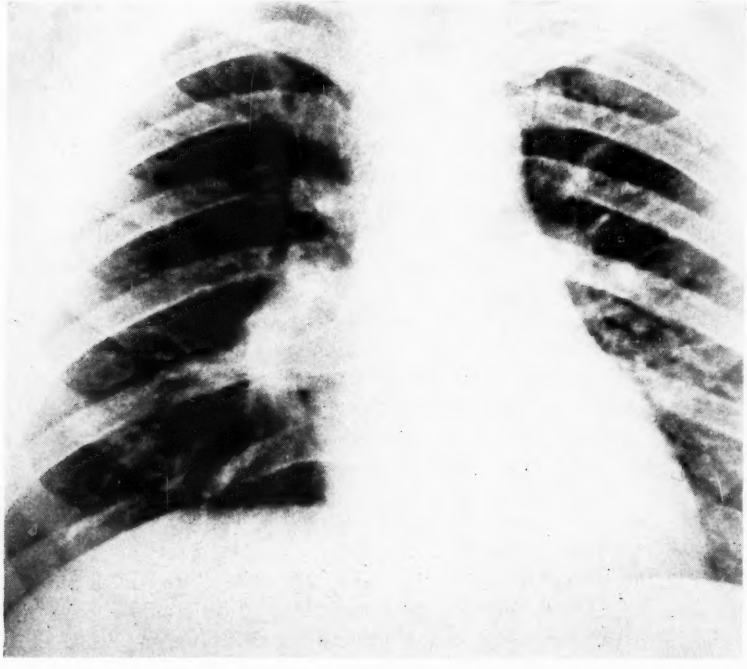

Fig. 2.—Case 1. Reproduction of roentgenogram made before amputation. The large solitary metastasis of the right middle lobe is clearly evident.

reported a successful pneumonectomy that was performed for a solitary metastasis invading the right main-stem bronchus. The primary source of this tumor was in the rectum, which had been removed eight months prior to admission. At the time of this case report, the patient gave evidence of involvement of the tumor elsewhere in the body. Blalock has two cases in which the patient has apparently benefited by extirpation of a solitary lung metastasis. In September,

Fig. 3.—Case 1. Lateral view shows the anterior position of the solitary metastasis in the right middle lobe.

1943, he performed a right total pneumonectomy on a 57-year-old man who had evidence of a tumor in the right lower lobe. Microscopic studies revealed the lesion to be a metastatic tumor, adenocarcinoma of the rectum. This patient had been subjected to bowel resection for the primary tumor in 1939. Blalock's second case is more remarkable in that the patient is 69 years of age. In December, 1942, she was operated upon at the Johns Hopkins Hospital and a resection of the cecum for carcinoma was performed. Several years later she developed symptoms of pulmonary disease and returned for re-examination. Roentgen studies revealed the presence of a tumor in the left lung. This lesion was discovered in August, 1946, approximately six months after the onset of her pulmonary symptoms. A left total pneumonectomy was performed in

December, 1946, and the patient made an excellent recovery. Tissue studies confirmed the diagnosis of a metastatic tumor arising from an adenocarcinoma of the cecum. Five months have elapsed since operation, and the patient appears to be in good health. In October, 1946, Flick operated upon a 36-year-old woman for a solitary tumor of the right middle lobe. The patient had complained of hemoptysis of six weeks' duration prior to operation and roentgenogram of the lung fields revealed the presence of the round neoplasm which measured 4 cm.

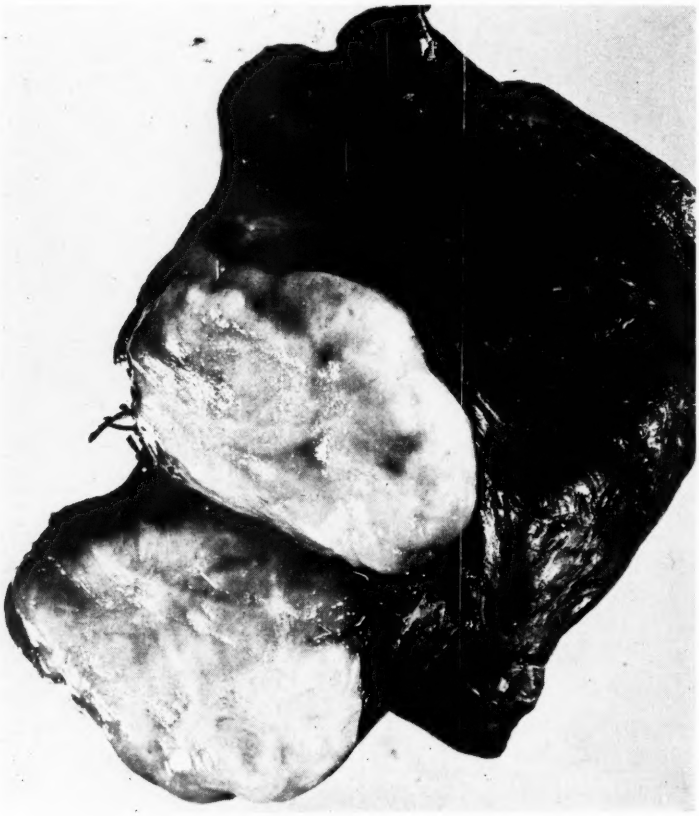

Fig. 4.—Case 1. The right middle lobe as it appeared immediately after operation. The solitary metastasis has been sectioned for tissue diagnosis.

in diameter. In 1938, the patient had been subjected to excision of a mass in her left thigh. The tissue diagnosis of liposarcoma was established. There were no local recurrences or distant metastases noted until the appearance of the pulmonary lesion eight years later. After lobectomy the diagnosis of metastatic liposarcoma was confirmed. The patient's immediate postoperative course was uneventful and at the present time she appears to be in excellent health.

## CASE HISTORIES

Three case histories are presented at this time because of their unusual interest. In each case, the primary tumor was identified and successfully removed. One patient had a solitary lung metastasis at the time of his admission. The other two developed solitary pulmonary lesions after discharge from the hospital. In each case the solitary lung metastasis was removed with apparent benefit to the patient.

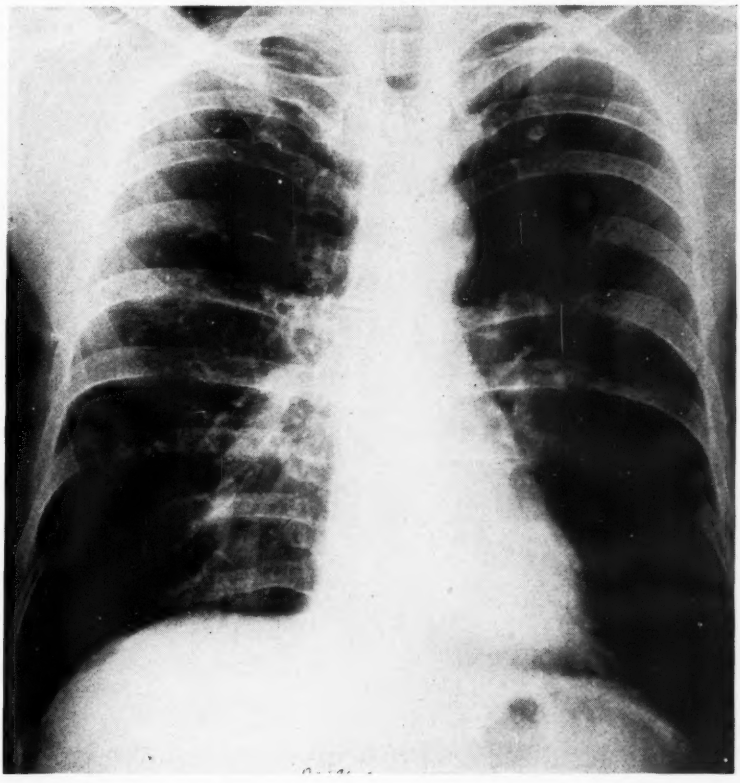

Fig. 5.—Case 2. A roentgenogram of the chest made in September, 1944, one month prior to bowel resection for adenocarcinoma of the sigmoid colon. There is no evidence of pulmonary metastasis demonstrated.

CASE 1.—A 23-year-old white soldier was admitted to the Walter Reed General Hospital on Aug. 22, 1945. The chief complaint on admission was a painless mass in the calf of his right leg. In 1943 he first noted that the right leg was slightly larger than the left. The swelling gradually increased until February, 1945. The past history was of interest in that he was hospitalized one week in July, 1944, for a sharp pain in the right chest, but there was no cough or sputum. Examination on admission showed marked enlargement of the right calf. The involved area was firm and showed skin striae. The right calf measured 20¾ inches and the left calf about 15 inches. Roentgen studies revealed a huge tumor extending

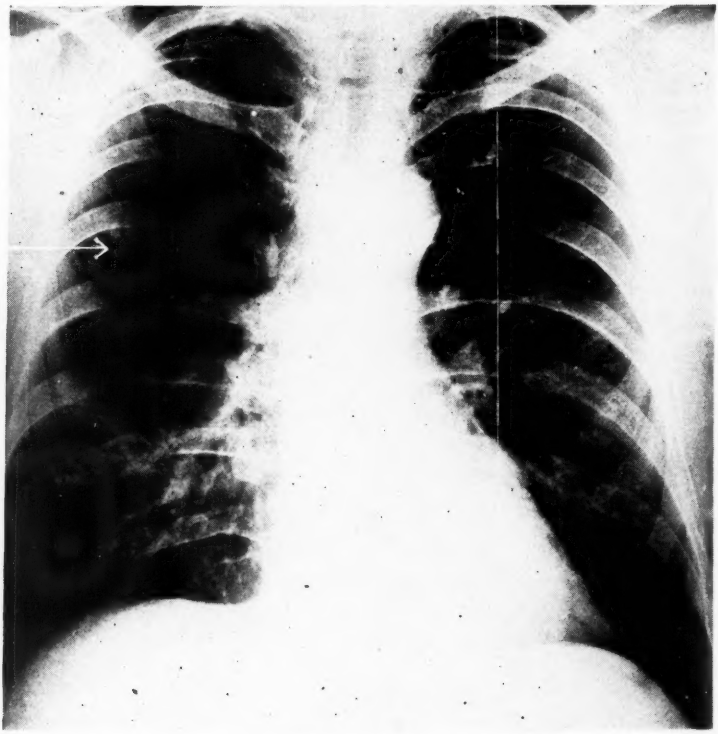

Fig. 6.—Case 2. Roentgenogram made in August, 1946, at the Walter Reed General Hospital. The solitary metastasis in the right upper lobe is easily identified.

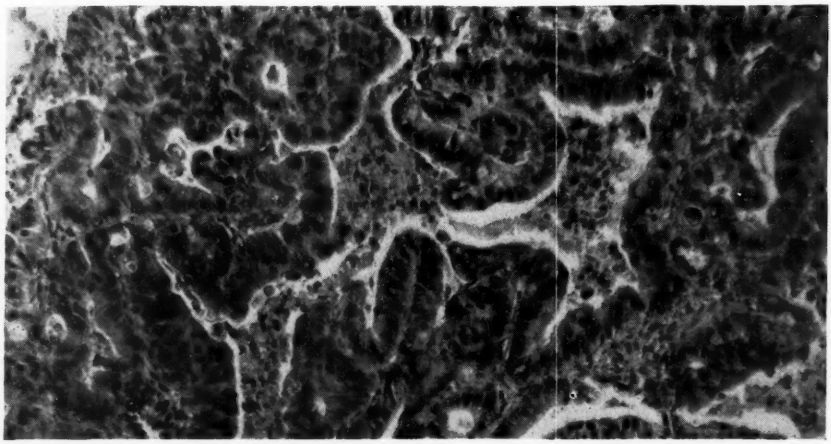

Fig. 7.—Case 2. A photomicrograph made from the solitary metastasis of the right upper lobe. Pathology diagnosis is adenocarcinoma, metastatic, from the large bowel.

from the popiteal space to a point 26 cm. below the knee joint. There was extensive calcification of the mass. The tibia and fibula appeared to be normal. Examination of the chest revealed a solitary lesion about 4 cm. in diameter that appeared to be in the right middle lobe. On Sept. 4, 1945, a supracondylar amputation of the right leg was performed. The tumor was found to be a lobulated mass that was fairly well encapsulated. There was evidence of infiltration of the neoplasm into the tibial vein. The final diagnosis was malignant synovioma with infiltration of the posterior tibial vein. On Nov. 7, 1945, an exploratory thoracotomy was performed. The principal finding at operation was a tumor mass that was localized to the

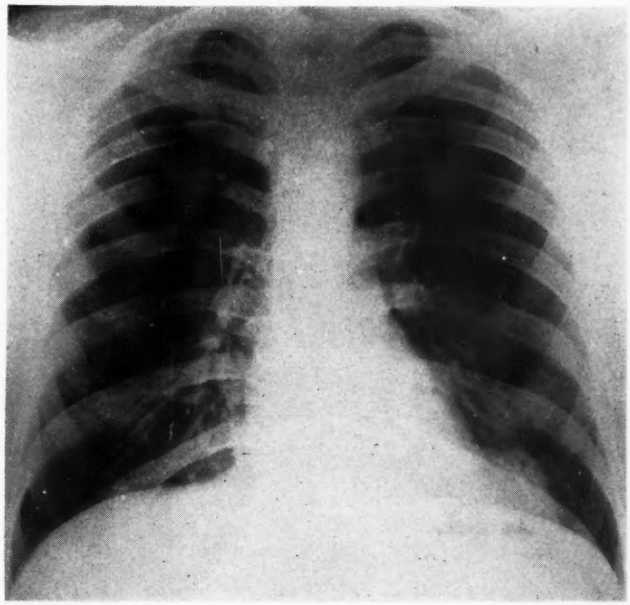

Fig. 8.—Case 3. Roentgenogram of the chest showing large solitary metastasis in left lower lobe.

right middle lobe. There was no palpable or visible evidence of other metastases. A right middle lobe lobectomy was performed. The diagnosis of metastatic synovioma was confirmed by the tissue study. This patient made an uneventful recovery from both procedures and was fitted for a prosthesis for his amputation. Careful studies revealed no evidence of other metastases or local recurrence. He was separated from the service in March, 1946. It is seventeen months since pulmonary resection and this patient appears to be in good health.

CASE 2.—The patient, a 51-year-old officer, was admitted to Walter Reed General Hospital on July 24, 1946. He was admitted primarily for administrative reasons after serving eighteen months of temporary limited duty. According to the patient, he had been hospitalized in September, 1944, because of lower abdominal cramps and the presence of bright red blood in the stools. After thorough examination, the diagnosis of an annular malignant lesion of the sigmoid bowel was established. On Nov. 13, 1944, the patient was operated upon. The lesion was excised with an end-to-end anastomosis of the colon. Exploration of the abdomen revealed no evidence of metastasis in the liver, aortic lymph nodes, or adjacent viscera. The pathologic diagnosis was adenocarcinoma of the sigmoid. This man made an uneventful post-

operative recovery. Roentgenogram studies of the thorax were obtained and the lung fields appeared to be normal. On Jan. 19, 1945, the patient returned to limited duty. He was readmitted on July 23, 1945, for a complete physical examination, including a roentgenogram of the chest. The officer states that he enjoyed excellent health and performed all duties without incident until he was recalled in January, 1946, for examination, and re-evaluation. At this time a small, nodular lesion was detected on the roentgen film and reported as being in the right upper lobe. The patient remained under observation until his admission to Walter Reed General Hospital in July, 1946. Careful examination revealed no evidence of local recurrence of the neoplasm or metastasis other than the solitary lesion in the right upper lobe. A careful review was made of all the chest films that had been made since his entrance to active duty

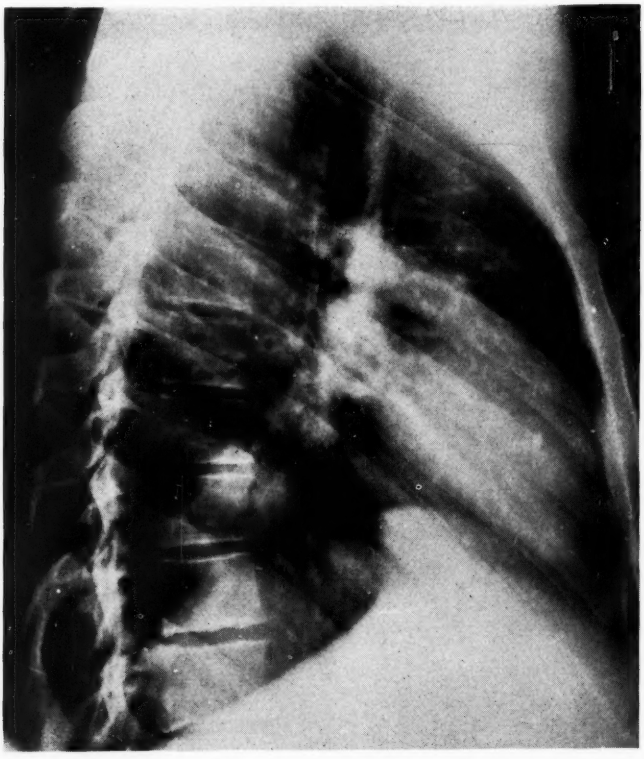

Fig. 9.—Case 3. Lateral view showing position of tumor in left lower lobe.

in 1942. The presence of a solitary metastasis was strongly suspected and surgical exploration was advised. The patient was operated upon Sept. 16, 1946, and an exploratory thoracotomy was performed. The lesion was easily identified in the right upper lobe and tissue was obtained for biopsy. Frozen section examination was reported as showing adenocarcinoma, probably metastatic. A right upper lobe lobectomy was performed and the patient made an uneventful recovery. Following operation a complete survey was made to uncover any other possible metastasis or recurrence of the original tumor. This survey included physical examination and roentgen studies of the thorax, skeletal system, gastrointestinal tract, and the

urinary system. At that time, there was no evidence to suggest the presence of disease. The final report from the department of pathology was adenocarcinoma, metastatic, probably from bowel. In February, 1947, the patient returned to the Walter Reed General Hospital with clinical evidence of an intercranial tumor. Craniotomy was performed and the lesion removed. In the gross examination the tumor appeared identical to the pulmonary lesion. Microscopic studies revealed that it, too, was adenocarcinoma, metastatic, probably from the large bowel. The patient has recovered from this second procedure and appears to be perfectly well. He has been released from the Army and has returned home, where he plans to resume his civilian occupation.

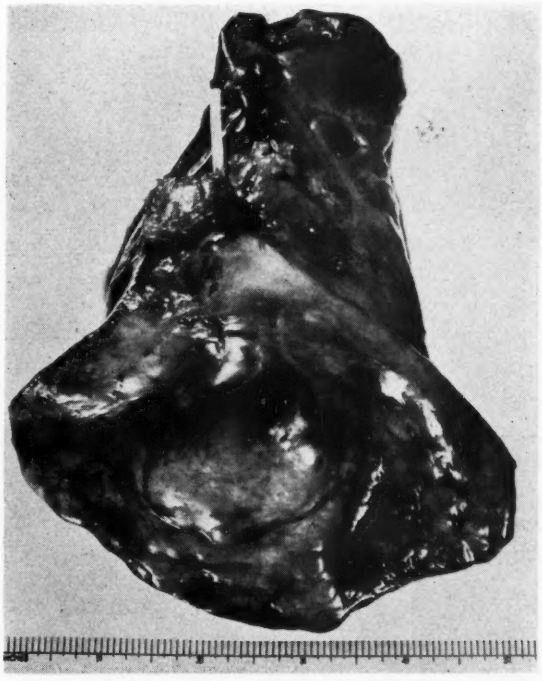

Fig. 10.—Case 3. Photograph of left lower lobe immediately following lobectomy. The tumor mass can be seen underlying the visceral pleura on the diaphragmatic surface of the lobe.

CASE 3.—The patient is a 26-year-old white man who was first admitted to the Walter Reed General Hospital in August, 1945. Prior to this admission he had been on overseas duty in the Pacific theater. In May, 1945, he first noted gradual enlargement of the left testicle. Following hospitalization, the impression of testicular tumor was made and confirmed by simple orchidectomy. Microscopic tissue studies were made in an army hospital in the Philippine Islands. The reports accompanying the patient gave the diagnosis of malignant testicular tumor, probably seminoma. The original specimen did not accompany the patient during evacuation to the Zone of the Interior. Following admission to Walter Reed General Hospital, complete physical examination was essentially normal. On Sept. 8, 1945, a radical gland dissection was performed to clean out the left iliac and abdominal retroperitoneal nodes. Careful microscopic studies of all removed lymph nodes failed to demonstrate

tumor tissue. After recovery from this procedure, the patient received intensive million-volt roentgen therapy to all the retroperitoneal lymph glands as prophylactic treatment. Radiation therapy was completed in November, 1945, and the following month the patient was discharged from the hospital and separated from military service. He states that he felt very well and returned to his former civilian occupation. In March, 1946, he reported back to the Walter Reed General Hospital for periodic examination. At this time a small round mass in the left lower lobe was demonstrated by roentgen examination of the thorax. It was the impression of the roentgenologists that this represented a metastasis from a probable seminoma and as such it would be very sensitive to radiation therapy. The patient received treatment with a total dose of 2,200 volts and remained under observation until October, 1946. The neoplasm did not respond to radiation therapy but continued to grow until it was the size of a

Fig. 11.—Case 3. Photograph of specimen after sectioning.

hen's egg. When seen by the thoracic surgical consultant, the patient appeared to be in excellent health and had no complaints other than vague discomfort in the left shoulder. There was no evidence of other metastases. On Oct. 24, 1946, exploratory thoracotomy was performed. A firm tumor which did not invade the visceral pleura was found in the periphery of the left lower lobe. In addition, there was a single hard lymph node invading the wall of the inferior pulmonary vein. No other evidence of neoplasm was discovered. A left lower lobectomy was performed without difficulty and the patient made an uneventful postoperative recovery. Microscopic diagnosis of the tumor and the involved lymph node was teratocarcinoma with chorionepithelioma component metastatic from testicular tumor. Approximately four months after operation the patient returned with clinical evidence of brain and skull metastases. Although no tissue biopsy has been obtained, it is evident that the patient has an extensive metastatic process at this time.

RÉSUMÉ OF CASES OF SOLITARY METASTASIS REPORTED IN THE LITERATURE

| CASE | TYPE OF PRIMARY TUMOR | SURGEON | APPEARANCE OF METASTASES | DATE OF OPERATION | PRESENT CONDITION |
|---|---|---|---|---|---|
| 1 | Renal adenocarcinoma | Churchill | 12 months prior to pneumonectomy | April, 1932 | Living and well |
| 2 | Uterine adenocarcinoma | Lindskog | 13 years after hysterectomy | 1943 | Living and well |
| 3 | Carcinoma of rectum | Raine | 8 months after excision of rectum | 1941 | Dead: visceral metastases nine months after pneumonectomy |
| 4 | Adenocarcinoma of rectum | Blalock | 4 years after bowel resection | March, 1943 | Living and well |
| 5 | Adenocarcinoma of cecum | Blalock | 3½ years after bowel resection | Dec., 1946 | Living and well |
| 6 | Malignant synovioma | Blades | Present at time of amputation primary tumor | Nov., 1945 | Living and well |
| 7 | Adenocarcinoma of colon | Effler | 18 months after bowel resection | Sept., 1946 | Solitary metastasis in brain removed Feb. 1947. Apparently well now |
| 8 | Liposarcoma of thigh | Flick | 8 years after excision of primary | Oct., 1946 | Living and well |
| 9 | Teratocarcinoma of testis | Effler | 7 months after gland dissection of retroperitoneal nodes | Oct., 1946 | Evidence of skull and cerebral metastases |

## CONCLUSION

The surgical treatment of the solitary lung metastasis is indicated in specific instances. It would seem reasonable that excisional therapy is indicated where the primary tumor has been extirpated and careful search reveals no manifestations of extension other than the solitary metastasis. It has been pointed out by Beers, and later by Bumpus, that metastases have been known to regress and disappear following removal of a primary renal carcinoma. This is an interesting and little understood phenomenon, but certainly it should not be considered a contraindication of surgery for the solitary metastasis. Likewise, it has been observed that solitary metastasis may appear early or very late, as much as ten years following removal of the primary tumor. It is difficult to understand why the development of the late metastasis is delayed; however, it is reasonable to assume that the chance for a cure in excision of the solitary metastasis would be better when the metastasis appears late.

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# EXTRAPLEURAL PNEUMOTHORAX

## A Late Follow-Up of Eighty-Two Patients Upon Whom Ninety-two Operations Were Performed

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EXTRAPLEURAL pneumothorax was first introduced as a method of surgical collapse for pulmonary tuberculosis by Tuffier in 1910. It was not widely used until Graf of Dresden in 1932 published a series of good results. Like most new surgical procedures, it was greeted with great enthusiasm and many operations were performed before sufficient experience had been gained in the selection of cases. Because of the frequency of complications, this enthusiasm has waned until it is now used infrequently in most sanatoriums. In June, 1940, a symposium on this procedure was held by the American Association of Thoracic Surgeons. In the discussion, doubts were expressed that the late results would be as satisfactory as the early.

This study is based on ninety-two extrapleural operations performed on eighty-two patients from October, 1937, to August, 1945. The time that has elapsed since operation varies from one year and six months to eight years, but the majority of patients have been followed five years or longer. With the exception of one patient, x-ray films of all were studied, lesions were classified, and progress reviewed. One patient is an Indian squaw, and as we have reports on her progress five years after her operation, she has been included. Age at the time of operation varied from 12 to 62 years. The 62-year-old patient is now 67 and working part-time. The pneumothorax was on the right side alone thirty-seven times, on the left side alone thirty-five times, and bilateral in ten cases.

### SELECTION OF CASES

No minimal cases were operated upon. The cases have been classified according to the National Tuberculosis Association classification as moderately and far advanced. Whether very far-advanced conditions should be operated upon is a controversial subject. In order to obtain information on this point, desperate risk patients with very extensive involvement or in poor clinical condition have been grouped together as a separate division, namely, "very far advanced."

*Discussion.*—(a) Very far advanced: While it is true that only one out of sixteen has been returned to full-time work, seven of these desperate cases have survived to date. This indicates that perhaps it was worth while subjecting the whole sixteen to operation. An example of this group is seen in Fig. 1.

(b) Far and moderately advanced: On reviewing the films today almost all the patients would have been suitable for a well-planned thoracoplasty and this would have eliminated the later hazards of the residual extrapleural space. A possible exception is illustrated in Fig. 2. This patient is an actress in whom a

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TABLE I.—PRESENT STATUS OF PATIENTS

| | MODERATELY ADVANCED | | FAR ADVANCED | | VERY FAR ADVANCED | | TOTAL | |
|---|---|---|---|---|---|---|---|---|
| | NO. | % | NO. | % | NO. | % | NO. | % |
| Deaths | 4 | 11.7 | 9 | 28.1 | 9 | 56.2 | 22 | 26.8 |
| Working full time | 15 | 44.1 | 9 | 28.1 | 1 | 6.2 | 25 | 30.5 |
| Working part time | 6 | 17.0 | 4 | 12.5 | 2 | 12.4 | 12 | 14.6 |
| Unfit for work | 4 | 11.7 | 9 | 28.1 | 3 | 18.7 | 16 | 19.5 |
| Other treatment necessary | 5 | 14.7 | 1 | 3.1 | 1 | 6.2 | 7 | 8.5 |
| Totals | 34 | 100 | 32 | 100 | 16 | 100 | 82 | 99.9 |

thoracoplasty with its resultant scar and deformity would have made it difficult if not impossible for her to earn a living.

*Analysis of Deaths.*—In this series of eighty-two patients, twenty-two have died (26.8 per cent). The average survival time was two years and three months. The latest died six years and nine months after operation. The deaths have been divided into early (those occurring within six weeks of operation) and late.

*Early Deaths (Four).*—One died of hemorrhage into the extrapleural space on the night of the operation. In one a large cavity was opened into at operation and bronchopleurocutaneous fistula and tuberculous cellulitis resulted and death occurred one month postoperatively. Another died one month after the operation from tuberculous colitis with fistula formation and generalized peritonitis. The fourth death occurred from rapid progression of tuberculous bronchopneumonia on the other side.

*Late Deaths (Eighteen Cases).*—(a) Ten patients died from progressive pulmonary tuberculosis due to unsatisfactory collapse obtained by extrapleural pneumothorax with subsequent spread of the disease and often enteritis.

(b) One patient succumbed to extension of disease on the opposite side despite a good collapse obtained on the extrapleural side.

(c) Four died as a result of bronchopleural fistula, three of them from pulmonary tuberculosis (Fig. 3), and one of a staphylococcus pneumonia and empyema the result of a spontaneous pneumothorax following aspiration for fluid.

(d) Miliary tuberculosis, hemorrhage from peptic ulcer, anoxemia of doubtful etiology each accounted for one death. These were verified by autopsy.

*Present Status of Extrapleural Space.*—There are sixty-seven extrapleurals on sixty living patients.

(a) Space maintained with air = 32.

(b) Space maintained with oleothorax = 19.

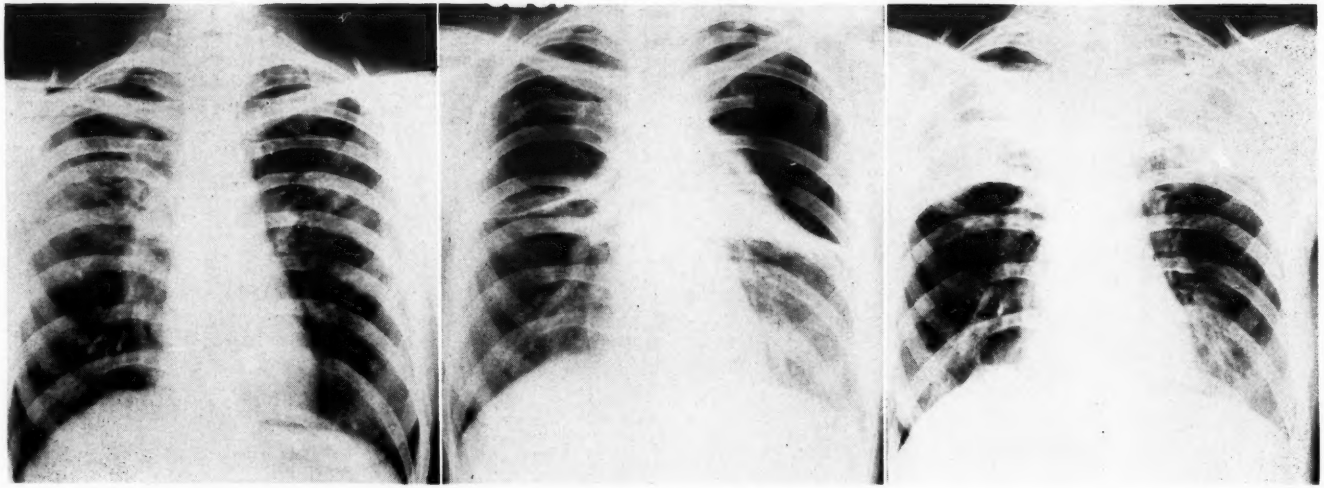
(c) Alive with re-expansion of lung = 4.

(d) Alive with persistent fluid usually positive = 5.

(e) Alive with further treatment on the extrapleural side = 7.

## DISCUSSION

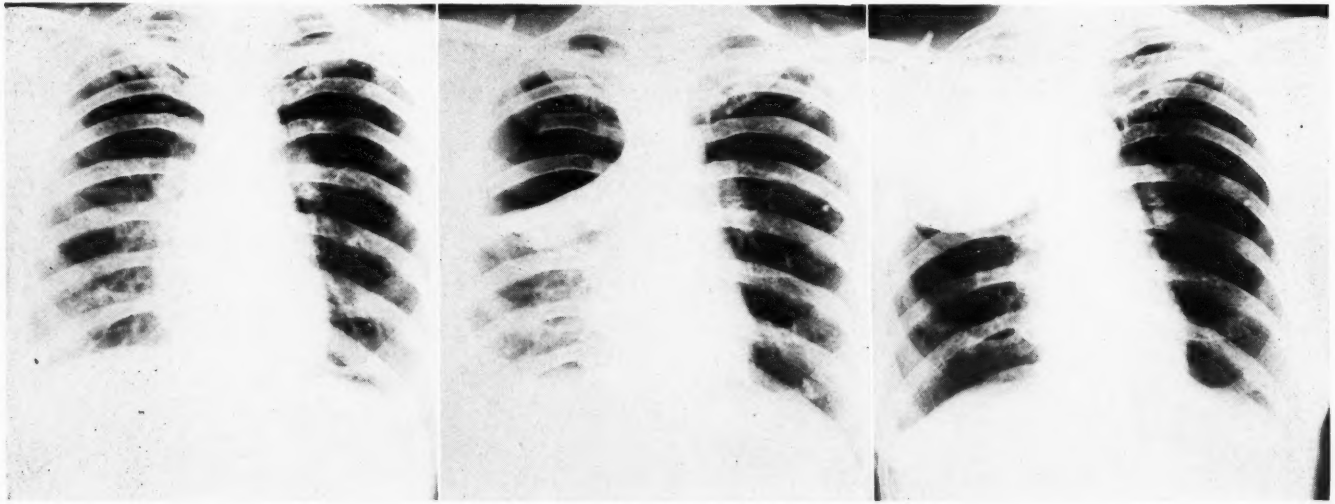
It is our belief that extrapleural spaces are best maintained by air refills. The disadvantage is the necessity of the patient's returning indefinitely but the fluid, which forms so frequently, can usually be easily controlled by increasing the pressures or decreasing the interval, provided it is recognized early.



*A.* *B.* *C.*

Fig. 1.—F., 34 years of age, was admitted June 5, 1938, with moderately advanced pulmonary tuberculosis, active bacillary. Pneumothorax was inefficient. The disease continued to spread and several hemorrhages occurred. Right extrapleural was done Feb. 5, 1941, and left extrapleural April 7, 1943. Present status is clinically well, sputum occasionally positive.

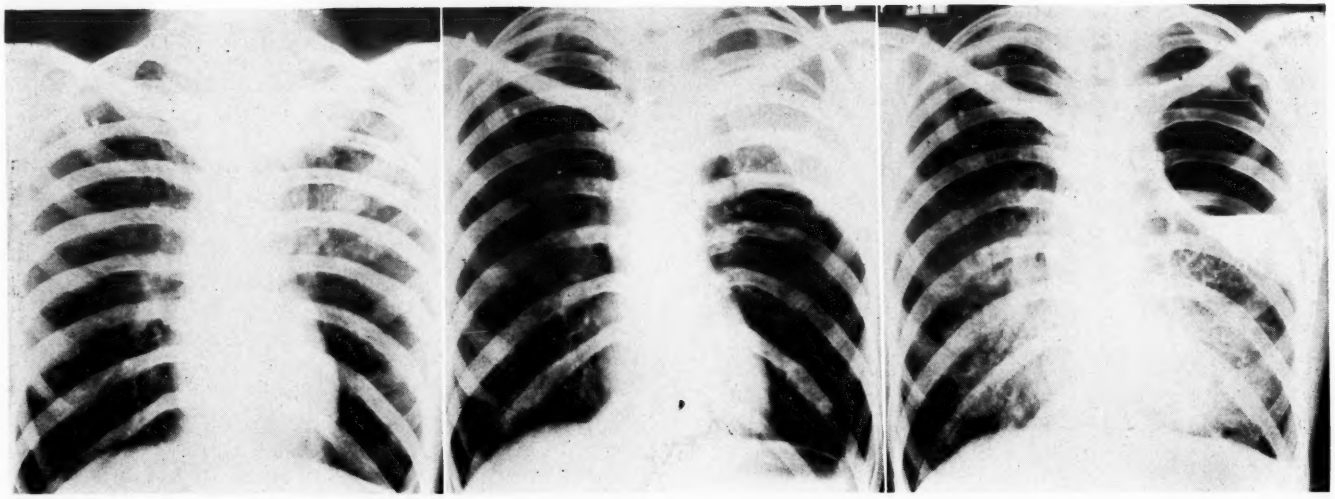
*A*, Before extrapleural pneumonolyses.
*B*, After bilateral extrapleurals.
*C*, After oil replacement.



*A.* *B.* *C.*

Fig. 2.—F., 43 years of age, was admitted Aug. 18, 1941, with moderately advanced pulmonary tuberculosis, active bacillary, and history of right-sided pleurisy. An actress, she was most anxious to avoid thoracoplasty. Right extrapleural was done Sept. 3, 1941. Present status is clinically well, no sputum. She recently circled the globe entertaining British troops.

*A*, Shortly after admission.
*B*, Following extrapleural.
*C*, After oil replacement and five-year follow up.



*A.* *B.* *C.*

Fig. 3.—F., 33 years old, was admitted June 19, 1939, with far advanced pulmonary tuberculosis, active bacillary. Planograms showed large cavity in left apex. Left extrapleural was done Nov. 1, 1941. Fluid postoperatively cleared with irrigations and was replaced with oil. Discharged Feb. 22, 1941, clinically well and sputum free.

Regular check-ups elsewhere without oil samples being taken. In Oct., 1944, she developed cough and sputum and two weeks later bronchopleural fistula. Readmitted Nov. 26, 1944, with extensive spread of disease, and died.

*A*, Before extrapleural.

*B*, Radiograph a few weeks prior to developing fistula.

*C*, After readmission.

Many patients with oil replacement have done well but tuberculous fluid may form with the oil. Radiologically and clinically this cannot be recognized until it attains a sufficient pressure to rupture into the lung (Fig. 3). If oil has been put into the extrapleural space, it seems safer to aspirate a sample every six months for tuberculosis culture to avoid this catastrophe.

It is generally recognized that an extrapleural pneumothorax results in a permanent collapse, although in the literature as late as April, 1943, this statement is found, "Every successful extrapleural pneumothorax reported is a patient saved from thoracoplasty and given the benefit of temporary collapse." Only four out of ninety-two (4.7 per cent) of our patients have re-expanded lungs. Ill-advised attempts to re-expand these lungs result almost invariably in the formation of an extrapleural empyema.

*Further Treatment.* —Seven patients have required further surgical treatment on the same side. Five have had thoracoplasties; three because of tuberculous empyemas and two because of insufficient collapse and persistently positive sputum. One of the latter has not been converted.

Two have had pneumonectomies for persistently positive sputum. One is well and her sputum is negative; the other is well clinically but sputum is still positive, presumably from an ulcer of the bronchial stump.

## CONCLUSION

1. Considering the type of case chosen, the results of extrapleural pneumothoraces in this series were reasonably satisfactory. Despite this fact, the procedure is thought to have a very limited place in the surgical therapy of pulmonary tuberculosis.

2. The operative mortality was higher than that of thoracoplasty but was due at the beginning to inexperience in the performance of the operation and in postoperative management.

3. The patients require care of a difficult kind indefinitely and are always liable to develop unpleasant complications.

4. The present view is that this procedure should usually be reserved for young, growing individuals who would probably develop considerable deformity following thoracoplasty and for a small group in whom the scar and deformity of thoracoplasty would debar them from a special vocation.

These operations were performed at the Toronto Hospital for Tuberculosis and I am indebted to Dr. Robert Janes and Dr. F. G. Kergin, Consultants on the Thoracic Surgical Service, and to Dr. M. J. McHugh, Medical Superintendent, for the privilege of making this report. I should also like to express my gratitude to Miss M. O'Sullivan, Record Librarian, for the difficult task of following the patients.

# AN EXPERIMENTAL STUDY OF THE EFFECT OF LIGATION OF PULMONARY VEINS IN THE DOG

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IN THE course of experiments designed to explore the possibility of creating a venous shunt between the systemic and pulmonary venous systems, it became desirable to utilize the proximal end of a divided pulmonary vein to one lobe in an end-to-end anastomosis. This would necessitate ligation of the distal end of the divided pulmonary vein to the lobe and would, in effect, be exactly equivalent to simple ligation of the pulmonary vein in so far as subsequent changes in the lobe itself are concerned. We wished to know, therefore, what changes in a pulmonary lobe are to be expected following simple venous ligation. In turning to the literature for the answer to this problem, we were surprised to find that, so far as we could discover, this simple experiment had never been fully exploited, and the answer was not fully known. Accordingly, a series of dogs were subjected to simple total ligation of the pulmonary vein from the upper lobe of the right lung and the subsequent pathologic changes in the lobe were observed at different time intervals following operation.

## REVIEW OF THE LITERATURE

Interest in pulmonary vein ligation first arose because it suggested itself as a therapeutic method in the treatment of tuberculosis. Tiegel's work,[1] published in 1911, has been offered as evidence that advanced pulmonary fibrosis is the end result of pulmonary vein ligation. However, in reviewing this study, it was apparent that Tiegel was not attempting complete venous ligation. He described placing silver wire rings around the pulmonary veins of rabbits and dogs to partially obstruct their lumina. In animals which survived, this was followed by an immediate intense engorgement of the pulmonary capillaries, accompanied by pulmonary hemorrhage. After weeks or months, firm pleural adhesions were found containing many blood vessels, and there was thickening of the pleura and alveolar septa. The lobes were said to be smaller, paler, and firmer than the normal lobes on the opposite side. In only two of his animals was complete ligation performed, and he noted that in many of the lungs histologic changes were minimal. Kawamura[2] confined his studies in rabbits to ligation of the pulmonary *artery* to the left lower lobe. In 1923, Schlaepfer[3] reported on the clinicopathologic aspects of air embolism following minor or major intrapleural manipulations. Experimental observations on two dogs following partial ligation of the pulmonary vein on one side were described, with special attention to the development of collateral venous channels which

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developed through parietovisceral adhesions and through enlargement of the bronchial veins. This author's subsequent work was confined to the effects of pulmonary arterial ligation.[4, 5]

We believe that the first clinical cases with pulmonary venous ligation were those reported by Kerschner[6] in 1931. Four patients with tuberculous cavities in the upper lobes underwent this operative procedure with mildly encouraging but not spectacular clinical results. No pathologic studies were available at the time of the report. In 1932 appeared the careful experimental studies of Mathes[7] and co-workers on the bronchial, pulmonary, and lymphatic circulations of the lung under various experimentally produced pathologic conditions. Among other conditions investigated, complete ligation of the pulmonary vein to one lobe of the lung was usually, although not invariably, followed by death of the animal in four or five days. The pleural cavity was found to be filled with a thin blood-stained effusion and the lobe was large, firm, and of a deep red, liverlike consistency. The bronchial artery appeared normal; the pulmonary artery was injected poorly with bismuth mass because of peripheral venous congestion. The number of animals used and the particular lobe whose vein was ligated were not stated.

This work apparently escaped the attention of European surgeons, because O'Shaughnessy,[8] in 1935, published three clinical cases with vein ligation using the report of Tiegel as experimental background. His patients had been followed less than one year, and no pathologic observations were available. In the same year, Valkányi[9] reported on three experimental and five clinical cases with pulmonary vein ligation. He tied the vein to the upper or middle lobe of the lung in three dogs. The mortality was not stated. The pathologic changes seen three to five weeks postoperatively were described by Professor Jàrmay. There was moderate shrinkage and a firm consistency of the lobe. Microscopically confluent areas of fibrosis were seen; the pleura was thickened, the alveoli were smaller and contained hemosiderin-laden phagocytes. Of the five patients with tuberculous cavities, one died postoperatively, two were unimproved, and two demonstrated moderate healing.

The study reported in 1938 by Ameuille[10] and his co-workers was concerned chiefly with the development of collateral venous channels following pulmonary vein ligation. Ten dogs were operated upon transpleurally. Six died in the immediate postoperative period. The remaining four were sacrificed at six weeks, four months, six months, and seven and one-half months, respectively. The pulmonary vessels were studied by injection. Firm vascular adhesions developing at the operative site and between the pleura and the chest wall contained enlarged collateral venous channels. There was no change in the pulmonary artery, but the bronchial artery and the artery of the pulmonary ligament seemed slightly enlarged. No description of the tissue changes found in the lung was given.

In his description of a two-stage operation for pneumonectomy in 1938, Rienhoff[11] states that if the pulmonary veins were ligated in the first stage, wet gangrene supervened. The observations which formed the basis for this statement were not described.

It would appear, therefore, that there is conflicting opinion as to the fate of a lobe of a lung following ligation of its veins, and that the only available evidence is comprised of the three animals of Valkányi and the unknown number of animals used by Mathes and associates. Observations were made, therefore, at various postoperative periods on eleven dogs in which the venous return from a single lobe had been ligated and cut, and on two animals in which the entire pulmonary vein to one side was ligated and cut.

## METHOD

Healthy mongrel dogs of medium or large size were used. In the performance of all surgical procedures, operating room technique and aseptic precautions were the same as used in the main operating room of the hospital. All procedures were done under endotracheal positive pressure ether anesthesia. Following operation, the animals were placed in individual cages until fully recovered, and then returned to the kennel runs. In the protocols, the term ligation will be used throughout to mean double ligation and complete division of the vessel. The postmortem tissues were fixed in 4 per cent formaldehyde, washed in tap water, cleared by dioxane, imbedded in paraffin, cut at 8 microns thickness, and stained by hematoxylin and eosin, Turnbull's blue, and Weigert's elastic tissue stain. Each animal served as its own control. In all cases none of the nonoperated lobes of the right lung and none of those of the left lung showed changes comparable to those observed in the lobes whose veins were ligated and severed. The necessity for dummy control operations was, therefore, eliminated.

## PROTOCOLS

### I. Single Lobe Ligations

Dog number V-1.—A stocky, slick-haired, brown dog weighing 22 kg.

May 24, 1946. Operation. Ligation of veins to right upper lobe.

May 27, 1946. Dog appears well but has moderate cough, with thick mucoid sputum.

May 31, 1946. Reoperation. Right upper lobe appears a deep dull red in color; is very firm, and feels solid. Lobe removed as a specimen. Middle lobe utilized for a different experiment, then removed. Lower lobe veins ligated. Moderate shock.

June 1, 1946. Dog found dead.

*Autopsy.*—Moderate amount of reddish exudate in pleural cavity. Right lower lobe solid, very hemorrhagic. Left lung normal.

*Microscopic Examination.*—(A) Right lower lobe (six to eighteen hours post-operative): The pleura showed fibrinopurulent pleuritis. The alveoli, bronchioles, and many bronchi were filled with edema fluid, packed erythrocytes, or inflammatory exudate (Fig. 3). The veins, venules, and capillaries were severely engorged. *Microscopic diagnosis:* (1) acute fibrinopurulent pleuritis; (2) pulmonary hemorrhage; (3) pulmonary hyperemia and edema; (4) focal bronchopneumonia.

(B) Right upper lobe (seven days postoperative): The pleura was covered by a thick layer of fibrin containing neutrophiles, nuclear debris, and swollen mesothelial cells, and penetrated at the edge by proliferated capillaries and fibroblasts (Fig. 4). Groups of alveoli beneath the pleura were surrounded and filled by proliferated fibroblasts. In several areas deeper alveoli and alveolar ducts showed loss of the outlines of their walls and were packed with edema fluid and erythrocytes, some including segmented neutrophiles and nuclear debris. Many bronchioles were filled with masses of fibrin enmeshing segmented neutrophiles. The alveolar capillaries and venules were engorged. Some of the larger veins showed thrombosis. *Microscopic diagnosis:* (1) organizing fibrinopurulent pleuritis; (2) pulmonary

Fig. 1.—Photograph of heart and lungs of dog sacrificed three days following ligation of the pulmonary veins to the right upper lobe.

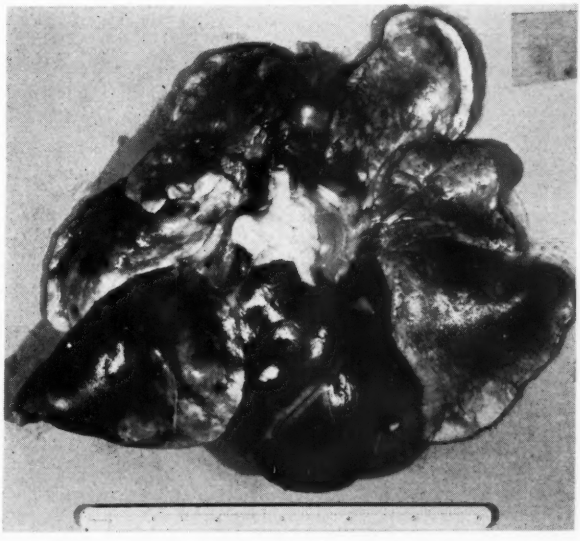

Fig. 2.—Photograph of heart and lungs of dog sacrificed 134 days following ligation of pulmonary veins to right upper lobe.

hemorrhage (with small scattered infarcts); (3) thrombosis of pulmonary veins; (4) organizing pneumonia.

DOG NUMBER V-2.—A black and white shaggy-haired dog weighing 21 kg.

June 2, 1946. Dog given 25 mg. dicoumarin.

June 3, 1946. Dog given 15 mg. dicoumarin. Prothrombin time, twenty seconds (normal). Operation. Ligation of pulmonary veins to right upper lobe.

June 4, 1946. Dog seems quite ill and weak, with severe cough producing blood-stained sputum.

June 5, 1946. Dog found dead.

*Autopsy.*—Right upper lobe was a deep greyish red and appeared solidified. Middle and lower lobes appeared atelectatic. Left lung normal.

*Microscopic Examination.*—The right upper lobe (two days postoperative) showed the pleura lightly covered with fibrinopurulent exudate. Many alveoli, ducts, bronchioles, and bronchi were crammed with erythrocytes. Some peripheral alveoli contained edema fluid; others were cystic and empty. The alveolar capillaries, venules, and veins were engorged. *Microscopic diagnosis:* (1) acute fibrinopurulent pleuritis; (2) pulmonary hemorrhage; (3) pulmonary hyperemia and edema; (4) bronchiolectasis.

DOG NUMBER V-3.—A large German shepherd dog weighing 30 kg.

June 6, 1946. Operation. Ligation of pulmonary veins to right upper lobe. Middle lobe vein used for an anastomosis.

June 7, 1946. Dog appears in good condition. Breathing is easy. Moderate cough.

June 8, 1946. Dog died at 8:30 A.M.

*Autopsy.*—The right chest cavity was filled with blood. The source of the bleeding was not determined. Anastomosis patent. No thrombosis. Upper lobe hemorrhagic and solidified. Middle lobe reddened and slightly shrunken. Left lung normal.

*Microscopic Examination.*—The right upper lobe (two days postoperative) showed changes almost identical with those described in dog V-2. *Microscopic diagnosis:* (1) acute fibrinopurulent pleuritis; (2) pulmonary hemorrhage; (3) pulmonary hyperemia and edema; (4) bronchiolitis and bronchitis, acute.

DOG NUMBER V-4.—A slick-haired, black dog weighing 15 kg.

Sept. 15, 1946. Operation. Ligation of veins to right upper lobe.

Sept. 17, 1946. Dog doing well. Mild cough.

Sept. 21, 1946. Dog fully recovered; asymptomatic.

Oct. 7, 1946. Dog in excellent health. Sacrificed.

*Autopsy.*—Wound well healed. Pleural cavities clean. Moderate firm adhesions of right upper lobe to parietal pleura and to mediastinum. Right upper lobe was shrunken, pale, and felt thickened and relatively airless. Other lobes normal.

*Microscopic Examination.*—Right upper lobe (twenty-three days postoperative). The pleura was thickened with connective tissue poor in elastic fibrils and containing new-formed capillaries. A few small groups of alveoli were collapsed. In many areas proliferated fibrous connective tissue and new capillaries were mingled with macrophages (containing brown pigment granules positive for iron) and lymphocytes. This tissue either filled alveoli and bronchioles, or surrounded and entrapped these structures. The larger veins showed organizing thrombi. *Microscopic diagnosis:* (1) fibrous pleuritis; (2) organizing pneumonitis with interstitial fibrosis and hemosiderosis; (3) thrombosis and recanalization of veins.

DOG NUMBER V-5.—A small, gray-black, long-haired dog weighing 14 kg.

Sept. 13, 1946. Operation. Ligated pulmonary veins to right upper lobe.

September 14, 1946. Dog making uneventful recovery.

October 7, 1946. Dog in good health. Sacrificed.

*Autopsy.*—Small superficial wound infection lower end incision. Pleural cavities clean. Adhesions between upper lobe and the wound. Right upper lobe slightly reddened and firm. Other lobes normal.

*Microscopic Examination.*—Right upper lobe (twenty-four days postoperative). The pleura showed thickening, with masses of neutrophiles, macrophages, and lymphocytes mingled

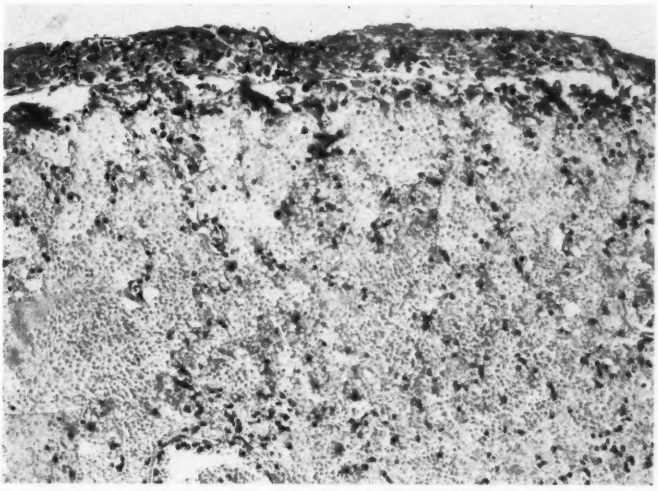

Fig. 3.—Dog V-1. Twelve hours. Fibrinopurulent exudate on pleura. Alveoli and alveolar ducts engorged and hemorrhagic. Hematoxylin and eosin stain. (×150.)

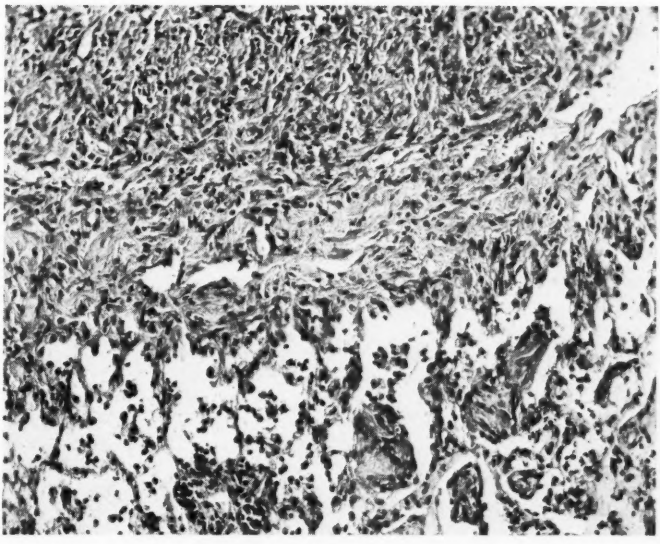

Fig. 4.—Dog V-1. Seven days. Granulation tissue and thickened pleura at top. Alveoli inclosing inflammatory cells and proliferated fibroblasts. Hematoxylin and eosin stain. (×150.)

with proliferated fibroblasts and capillaries, as well as new fibrous tissue poor in elastic fibrils. Alveoli, alveolar ducts, and bronchioles showed widespread collapse. The more superficial ones contained proliferated fibroblasts intermingled with leucocytes. Venules and capillaries were mildly engorged. Macrophages were present, containing iron-positive pigment. *Microscopic diagnosis:* (1) chronic pleuritis; (2) atelectasis; (3) organizing pneumonitis with focal hemosiderosis.

Dog number V-6.—A German shepherd dog weighing 18 kg.

Sept. 3, 1946. Operation. Ligation of the pulmonary veins to the upper right lobe.

Sept. 9, 1946. Dog has made excellent recovery.

Oct. 7, 1946. Dog in good health. Sacrificed.

*Autopsy.*—Wound well healed. Pleural cavities normal. Very thick adhesions between upper lobe and the chest wall and mediastinum. Upper lobe appeared whitish, was shrunken, and felt firmer than normal, but not solid.

*Microscopic Examination.*—Right upper lobe (thirty-four days postoperative) (Fig. 5). The pleura showed thick fibrous connective tissue poor in elastic fibrils and inclosing new capillaries and venules. Much fibrous connective tissue was proliferated in the stroma, thus obliterating or entrapping alveoli, alveolar ducts, and bronchioles. Many hemosiderin macrophages were intermingled in this tissue and were free in a few alveoli. Organizing thrombosis of larger veins was present. *Microscopic diagnosis:* (1) fibrous ("vascular) pleuritis; (2) interstitial fibrosis and hemosiderosis; (3) thrombosis of pulmonary veins.

Dog number V-7.—A brown collie bitch weighing 17 kg.

Aug. 30, 1946. Operation. Ligation of pulmonary veins to right upper lobe.

Sept. 4, 1946. Dog has had slight cough.

Sept. 10, 1946. Dog seems entirely well.

Oct. 7, 1946. Dog has remained in good health. Sacrificed.

*Autopsy.*—Wound was well healed. Pleural cavities clean. Many firm adhesions between chest wall and upper lobe. Right upper lobe was pale, moderately shrunken, and felt relatively airless. Other lobes were normal.

*Microscopic Examination.*—Right upper lobe (thirty-eight days postoperative). Similar to dog number V-6. *Microscopic diagnosis:* (1) fibrous ("vascular") pleuritis; (2) interstitial fibrosis and hemosiderosis; (3) thrombosis of pulmonary veins.

Dog number V-8.—A light brown chow dog weighing 26 kg.

May 27, 1946. Operation. An end-to-end venous anastomosis made using right upper lobe vein. The distal end of this vein ligated.

May 29, 1946. Dog in good condition. Has not developed cough.

July 2, 1946. Operation. Right chest opened in order to perform a second and unrelated experimental procedure. There were dense adhesions surrounding the upper lobe. The lobe was dark in color and seemed partially solidified. A generous biopsy of the right upper lobe was taken for examination.

*Microscopic Examination.*—Right upper lobe (forty-five days postoperative). The pleura was greatly thickened by a vascular fibrous connective tissue poor in elastic fibrils. Many alveoli, alveolar ducts, and bronchioles were collapsed; very few were filled with erythrocytes and edema fluid. Many macrophages (Fig. 6) containing iron-positive pigment were seen. The larger veins showed organized thrombosis. *Microscopic diagnosis:* (1) fibrous pleuritis; (2) atelectasis; (3) focal hemorrhagic edema and hemosiderosis; (4) thrombosis and recanalization of pulmonary veins.

Dog number V-9.—A short-haired, black and white dog weighing 17 kg.

Aug. 15, 1946.—Operation. An end-to-end anastomosis using right upper lobe vein. Pulmonary end of vein ligated.

Aug. 20, 1946. Dog making uneventful recovery.

Oct. 25, 1946. Dog has remained healthy. Sacrificed.

*Autopsy.*—Wound well healed. Pleural cavities clean except for adhesions between right upper lobe and the chest wall. Right upper lobe pale, slightly firm. Other lobes normal.

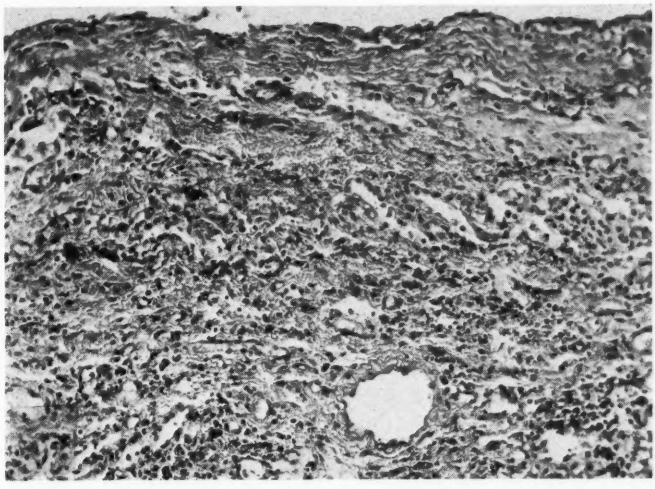

Fig. 5.—Dog V-7. Thirty-four days. Thickened pleura, collapsed alveoli and alveoli ducts, interstitial fibrosis. Hematoxylin and eosin stain. (×150.)

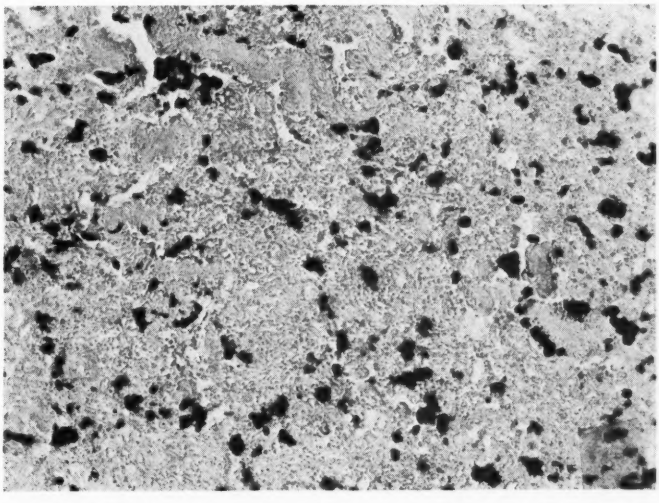

Fig. 6.—Dog V-8. Forty-five days. Collapsed alveoli and alveolar ducts. Many hemosiderin macrophages. Iron stain, Turnbull's blue method. (×150.)

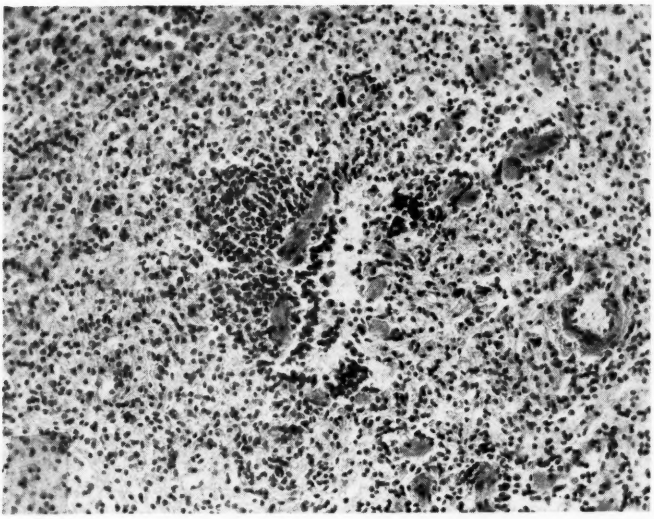

Fig. 7.—Dog V-9. Seventy-one days. Bronchiole at center surrounded by collapsed alveolar ducts and alveoli. Hematoxylin and eosin stain. (×150.)

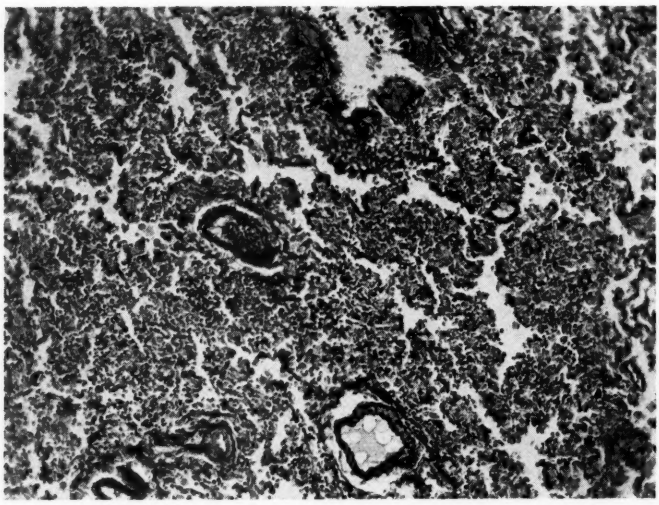

Fig. 8.—Dog V-9. Seventy-one days. Atelectasis. Weigert's elastic tissue stain. (×150.)

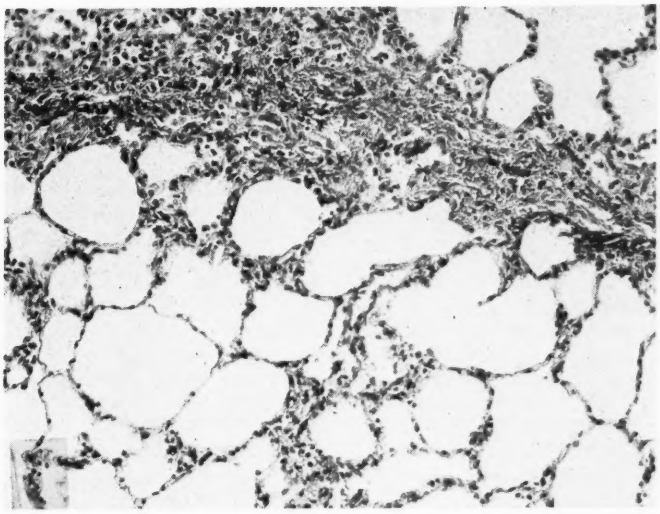

Fig. 9.—Dog V-11. One hundred thirty-four days. Band of interstitial fibrosis at top. Re-expanded alveoli in lower half. Hematoxylin and eosin stain. (×150.)

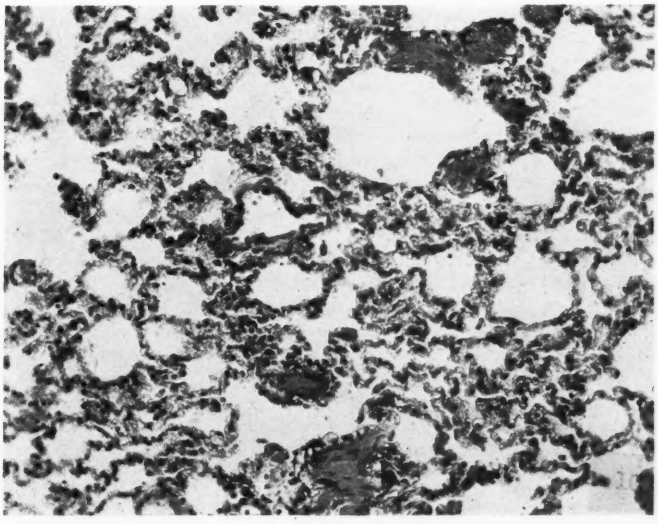

Fig. 10.—Dog V-11. One hundred thirty-four days. Normal lobe of left lung for comparison with Fig. 7. Hematoxylin and eosin stain. (×150.)

*Microscopic Examination.*—Right upper lobe (seventy-one days postoperative) (Figs. 7 and 8). The pleura was thickened with a chronic suppurative fibrotic reaction. Many alveoli, alveolar ducts, and bronchioles, were collapsed; others were surrounded by strands of proliferated fibrous tissue. *Microscopic diagnosis:* (1) chronic suppurative fibrous pleuritis; (2) atelectasis; (3) focal interstitial fibrosis.

DOG NUMBER V-10.—A tan collie dog weighing 20 kg.

Aug. 12, 1946. Operation. Ligation of pulmonary veins to right upper lobe.

Aug. 15, 1946. Dog has mild productive cough.

Dec. 2, 1946. Dog has remained in excellent health. Sacrificed.

*Autopsy.*—Wound well healed. Upper right lobe was adherent to chest wall and to mediastinum with fine adhesions, which were dense only in the region of the chest incision. The right upper lobe appeared slightly shrunken, but was almost normal in color, soft to touch, and crepitant. Other lobes were normal.

*Microscopic Examination:* Right upper lobe (111 days postoperative). The pleura was thickened with vascular fibrous tissue. Many alveoli, alveolar ducts, were well expanded. In several areas thin strands of fibrous connective tissue infiltrated with lymphocytes and iron-positive pigment-laden macrophages, were proliferated around alveoli, alveolar ducts, bronchioles, and in the septa. The large veins showed recanalizing thrombosis. *Microscopic diagnosis:* (1) fibrous pleuritis; (2) interstitial fibrosis and hemosiderosis; (3) thrombosis and recanalization of pulmonary veins.

DOG NUMBER V-11.—A large, black dog weighing 26 kg.

July 30, 1946. Operation. Ligation of pulmonary veins to right upper lobe.

July 31, 1946. Dog has cough productive of blood-tinged sputum.

Aug. 5, 1946. Dog recovered from operation. Cough disappeared.

Dec. 2, 1946. Dog has remained in good health. Sacrificed.

*Autopsy.*—Wound firmly healed. Right upper lobe adherent to chest wall with breakable adhesions. The lobe appeared normal in size, shape, color, and consistency. Other lobes normal.

*Microscopic Examination.*—Right upper lobe (134 days postoperative) (Figs. 9 and 10). The pleura was thickened with vascular connective tissue poor in elastic fibrils. Occasional iron-positive pigment-laden macrophages were seen. Strands of fibrous connective tissue extended between some alveoli and in the septa, but most of the alveoli were normally patent. It was estimated that the lobe was 80 per cent aerated. *Microscopic diagnosis:* (1) fibrous pleuritis; (2) interstitial fibrosis and hemosiderosis; (3) thrombosis and recanalization of pulmonary veins.

### II. ENTIRE LUNG LIGATIONS

DOG NUMBER L-1.—A small, slick-haired bitch weighing 12 kg.

Sept. 25, 1946. Operation. The left pulmonary vein to the entire left lung was ligated.

Sept. 26, 1946. Animal died at twenty-four hours following operation. She showed extreme weakness, pallor of the mucous membranes, dyspnea, and cough productive of bloody sputum. She presented the picture of progressive shock.

*Autopsy.*—Pleural cavity on left contained blood-stained fluid. The entire left lung was dark red, completely solidified, and gave the appearance of liver.

*Microscopic Examination.*—(One day postoperative.) The appearance in all of the left lobes was similar to that seen in the right lower lobe of dog V-1. *Microscopic diagnosis:* (1) acute fibrinous pleuritis; (2) pulmonary hemorrhage, pulmonary hyperemia, and edema; (3) bronchopneumonia; (4) thrombosis of pulmonary veins.

DOG NUMBER L-2.—A brown, long-haired bitch of collie extraction, weighing 11 kg.

Sept. 26, 1946. Operation. Ligation of the entire pulmonary venous return from the right lung.

Sept. 27, 1946. Animal is very weak and is coughing up blood.

Sept. 29, 1946. Animal died three days following operation, and became progressively weaker with increasing pallor.

*Autopsy.*—The entire right lung is a dark red color, completely solidified, and quite heavy.

*Microscopic Examination.*—The right lung (3 days post-operative).

*Microscopic diagnosis.*—(1) Acute fibrinous pleuritis; (2) pulmonary hemorrhage, pulmonary hyperemia, and edema; (3) bronchopneumonia; (4) thrombosis of pulmonary veins.

## COMMENT

These experiments indicate that healthy dogs may have the veins from the right upper lobe ligated and divided and survive the operation, probably indefinitely. Of the three deaths in this series occurring following operation, two were the result of an additional but unrelated experimental procedure (dogs V-1 and V-3), and one (V-2) was in an animal under the effect of dicoumarin. We have never had an animal survive a major operative procedure while under the effect of this drug. Eight dogs survived from 23 to 134 days, and were then sacrificed.

On the other hand, ligation of the entire venous return from a lung was fatal within three days in two animals (L-1, L-2). These animals appeared to die of blood loss and shock. The pathologic findings in these lungs were identical with those seen in the single lobe following venous ligation. The difference between survival and death, therefore, would appear to be quantitative, and is related, we think, to the volume of blood loss as pulmonary hemorrhage.

The sequence of events following ligation and division of the veins of one lobe of a lung may be briefly sketched. The first reactions in the lobe include a fibrinous or fibrinopurulent pleuritis with adhesions of the lobe to the parietal pleura. The lobe is pumped full of blood by the intact arteries to it. Consequently, severe hyperemia, hemorrhage, and edema are noted, especially involving the aveoli, alveolar ducts, and bronchioles. Along with the reduced vitality of the pulmonary parenchyma, bronchopneumonia becomes an accompanying reaction. As a result of their ligation, thrombosis occurs in the veins to the lobe.

The process of recovery from these acute changes includes the establishment of adhesions between the visceral and parietal pleura through organization of the acute pleuritis and the formation of new blood vessels, including capillaries, venules, and arterioles to furnish a collateral blood supply, especially venous. Along with this reaction, blood monocytes coming into the arteries migrate from the alveolar capillaries into the alveoli and alveolar ducts and pick up cell debris, especially broken down erythrocytes and the degradation products of hemoglobin, so well demonstrated by the abundant hemosiderin in numerous macrophages, mainly in alveoli, alveolar ducts, and bronchioles early and chiefly in interstitial fibrous connective tissue later. Granulation tissue grows out into alveoli, alveolar ducts, and bronchioles to organize contained exudate. In addition, air is evidently resorbed from some alveoli and alveolar ducts. Widespread atelectasis results from the emptying of the content of these structures by both the scavenging of the hemorrhagic and inflammatory debris and the resorption of edema fluid and residual air. As the collateral blood supply established by the pleural adhesions becomes more abundant in the later stages, especially as seen in dogs V-8 and V-10, the still intact arterial blood vessels are able to vascularize the lobe, especially the alveolar

capillaries, and the still intact bronchial tree is able to admit air for the re-expansion of the lobe. The atelectatic areas then largely disappear, the re-expansion beginning first at the periphery of the lobe and then extending centrally. The granulation tissue within the alveoli, alveolar ducts, and bronchioles is either resorbed or incorporated into the interstitial fibrous connective tissue.

The final result after three or four months is a lobe at least 80 per cent re-expanded and apparently functioning with residual vascularized pleural adhesions and focal interstitial fibrosis and hemosiderosis. The thrombi in the proximal ends of the severed veins to the lobe become organized and the veins are recanalized to different degrees.

## SUMMARY

1. The pathologic changes in the right upper lobe of the lungs of eleven healthy dogs observed at increasing intervals following ligation and division of the pulmonary veins to that lobe are described.

2. Healthy dogs may survive indefinitely following ligation of the veins to a single lobe, but ligation of the veins to the entire lung in two animals was fatal.

3. There is no significant death of pulmonary tissue following venous ligation. The primary reaction is severe pulmonary engorgement and hemorrhage. Gradually, in a period of about four months, this hemorrhage is resolved, the accompanying intraluminal and interstitial fibrous reaction is absorbed, and with the development of collateral venous channels through adhesions, the lung returns toward normal, approaching full functional activity.

The authors wish to express their appreciation of the excellent technical assistance of Dr. Charles Monroe.

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# BRONCHIECTASIS IN SERVICE PERSONNEL

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THIS is a report of the surgical treatment of bronchiectasis undertaken at Christie Street Hospital, Toronto, from 1941 to 1945, inclusive. Christie Street is the local hospital under the Department of Veterans Affairs. Throughout the war years, many men of all services were treated here, both during and after discharge. The surgical treatment was carried on under the supervision of Dr. Norman Shenstone, while the investigation was the responsibility of the Chest Clinic, of which Dr. George Anglin was the chief physician.

There were in this group seventy-five patients, on whom eighty lobectomies were performed. On the whole, these were young men who had been in good physical condition fairly recently. The ages varied from 18 to 47; and averaged 24, with well over half younger than 25 years. The service in which they had enlisted did not seem to have any bearing on the disease, though thirty were in the R.C.A.F., thirty-two in the Army, ten in the Navy, and one was a Nursing Sister.

The site of the disease is of some interest. The left lower lobe was involved in fifty-two cases, and in four of these there was an associated disease of the lingual lobe. The right lower lobe was diseased in thirty-three cases, with an associated middle lobe in seven of them. There were ten with bilateral involvement. Three of these have had complete excision of disease, with a fourth, at the moment, in preparation for the second operation. In two instances, the right middle pobe was found to be involved, and was removed at a second operation.

## PAST HISTORY

In reviewing the past histories of these individuals, it is very difficult to be absolutely sure of the presence or the extent of respiratory disease before enlistment. Ostensibly, they were all in good physical condition, with no major respiratory complaint and with an x-ray of the chest declared to be negative at the time of enlistment. In nineteen patients there was a history of definite respiratory infection prior to 1939. This date was taken arbitrarily as being about the time of earliest enlistment in the Canadian Armed Services. This infection varied from a series of severe head colds, to recurrent attacks of pneumonia, to a chronic cough with sputum over a period of years which was a feature in only three cases.

The next group of twenty-two cases showed no history of pneumonia, and no definite major respiratory infection before 1940. However, all had had frequent upper respiratory infections since enlistment, and many had developed cough and sputum following these infections. They were not hospitalized, as a rule, until the time bronchiectasis was diagnosed.

Read (by title) at the Twenty-Sixth Annual Meeting of The American Association for Thoracic Surgery, Detroit, Mich., May 29, 30, and 31, 1946.

TABLE I

| | | |
|---|---|---|
| Age | 18 to 47; average, 24 | |
| *Service* | | |
| | R.C.A.F. | 30 |
| | Army | 32 |
| | Navy | 10 |
| | Nursing Sister | 1 |
| *Site* | | |
| | Left lower | 52 |
| | Lingual | 4 |
| | Right lower | 33 |
| | Middle | 7 |
| | Bilateral | 10 |

TABLE II.

| PAST HISTORY | NO. |
|---|---|
| Respiratory infection before 1939 | 19 |
| Frequent upper respiratory infection | 22 |
| Pneumonia twice or more | 21 |
| Pneumonia once | 19 |

There were another twenty-one patients who gave the usual history of more than one attack of pneumonia, followed by persistent cough and sputum. There were nineteen patients who had no previous major respiratory infection, had had one attack of pneumonia only, since 1940, and had a persisting cough and sputum following this one attack. It is suggested that this is a virus type of pneumonia. This is a very important group, as their history supports the hypothesis that bronchiectasis can and does develop as a relatively acute disease, and is not one necessarily of many years' duration. In reviewing the whole series of seventy-five patients, it is seen that forty-one, or well over half, had had no major respiratory infection prior to enlistment, and had developed bronchiectasis over a brief period of one to four years. On checking more closely, it is found that fourteen of these gave a history of six months or less before admission to hospital and diagnosis of bronchiectasis.

## SYMPTOMATOLOGY

At the time of their final admission to hospital for investigation and assessment, all patients complained of cough and sputum. The severity of cough and the amount of sputum varied considerably, but there is no doubt that there were relatively few who had the copious foul-smelling sputum previously associated with bronchiectasis. Other symptoms were absent in the great majority, but there was a history of: hemoptysis in eight, loss of weight in six, loss of strength in nine, shortness of breath in seven, and pain in chest in four.

Physical signs, as usual, were not outstanding, but râles were heard over the affected area in practically all the patients. There were frequent observations of decreased movement and dullness in the involved base. A routine examination of the upper respiratory passages and sinuses was made in each case by the otolaryngologist. It was a distinct surprise to note that the examination was negative in practically every case. Only one patient was diagnosed as having pansinusitis. He also had bilateral bronchiectasis. Routine bronchoscopic exam-

ination was also done, and no tumors were found in this series. There was one bronchial stenosis. The great majority showed only purulent discharge from the involved area. Bronchograms were, of course, checked very carefully for localization and extent, with particular attention to the lingula and the right middle lobes.

### OPERATION

Preoperative preparation was very much the same in all cases. The patients were on full diet with extras; they had constant postural drainage for varying lengths of time, depending on the amount of sputum. Any foci of infection were cleared up as well as possible. Their blood was typed, and at least two pints of blood obtained for the operation. Anesthesia was intratracheal ether and oxygen, or cyclopropane and oxygen. In all cases the posterolateral incision was made, and in the majority, the patient was placed in the lateral position. In a very few of the more recent cases, the prone position was used, with a great improvement in the aeration of the good side. The diseased sections of the lung were removed by dissection lobectomy in all but one instance, in which there had been chronic pulmonary infection for many years. When feasible, the cut margins of the pleura were sutured over the hilar structures. In thirty-five cases, sulphathiazole powder was dusted in the pleural cavity; and in the last forty-five, penicillin and sulphathiazole powder. A closed intercostal drain was inserted by a stab wound low in the thorax, the ribs approximated with wires, and the intercostal muscles sutured. Oxygen was administered postoperatively for at least twelve hours, and often for twenty-four hours. The foot of the bed was raised for those who had had much sputum or bilateral disease. After eight hours the patients were turned every two hours. The drainage tube was removed after forty-eight hours, and it was rarely necessary to aspirate the chest later. Most of the patients were out of bed in a week, and many more in ten days. The majority were ready to return to the chest clinic for convalescence three weeks after operation. Here the lung expansion was checked carefully and encouraged by supervised breathing exercises. When the patients were ready to leave hospital, they were usually given three months' convalescent leave, reporting to the outpatient clinic regularly during that time.

### COMPLICATIONS

The commonest complication postoperatively was empyema, which occurred seven times. In three of these cases, the infection was overcome by aspiration and injection of penicillin, and cleared up quite readily. In the other four, rib resection was done. In one, the wound was healed in two months' time; in the second, in three months' time. They had no further trouble. The third empyema drainage lasted four months, but then healed without further incident. The fourth empyema requiring drainage followed the resection of right middle and lower lobes. In that case, there was no definite separation between upper and middle lobes, and it was done at a time when we were making the separation by clamping, cutting, and oversewing the cut margin. This prevented satisfactory expansion of the upper lobe and the residual cavity became infected two months

postoperatively. It is still draining. I believe it is of interest to note that five of these infections occurred in the period when we were using sulphathiazole alone, and only two when we used penicillin and sulphathiazole.

Bronchopleural fistula occurred only once in this series. This man had had a long history of chronic pulmonary disease and it was thought advisable to use the lung tourniquet in removing his right lower lobe. He developed an empyema one week after the operation. This was being treated by aspiration and injection of penicillin when, a week later, he demonstrated a bronchopleural fistula by coughing up the suppuration. Fortunately, he was able to keep the cavity empty by postural drainage and it gradually diminished in size by expansion of the adjacent lung. It was never thought necessary to drain the empyema externally. His chest eventually cleared up completely. He reported recently as being in fair health, with some residual cough and sputum, but working full time at a light job.

The only other complications were pneumonia in two cases, and thrombophlebitis in one case. One of the pneumonia cases was considered to be a lipoid pneumonia, due to lipiodol retained in the good lung. The other occurred in the only patient who was diagnosed as having a pansinusitis preoperatively. This may have had some effect on his postoperative course. Both of these were out of hospital within two months. There seemed no special reason for the development of the thrombophlebitis. It had completely disappeared when the patient was examined in clinic three months postoperatively, with no further complications.

### MORTALITY

There was one death in this group of eighty operations. This young man of 20 years had had chronic cough with sputum for twelve years. He had a history of very frequent colds, but in spite of this he enlisted in the R. C. A. F. in October, 1943. He went overseas in June, 1944, but because of frequent respiratory infections, he was repatriated in May, 1945, and admitted to Christie Street Hospital in June. Investigation there showed bilateral bronchiectasis, definitely more marked in the right middle and lower lobes. He was treated in the chest clinic for three months, when he was advised to have right middle and lower lobectomy. This was started on September 11, but the anesthetist had very early difficulties with large amounts of tenacious mucopurulent discharge, hence, the operation was stopped before the chest was opened. He was referred back to the chest clinic, and every effort was made to clear out the bronchial tree. It was considered that definite progress was made, and about three months later a second attempt was initiated. Bronchoscopic suction was employed immediately before the operation and the anesthetist made every effort to keep the airway open. There was not quite so much discharge on this occasion, although there was never a perfectly clear aeration. Toward the end of the dissection of the hilum, more respiratory difficulty was encountered, and the patient died on the table. Autopsy showed plugging of the opposite bronchus with mucopus, and almost complete pulmonary collapse. Since that time we have used the prone position in preference to the lateral, and think that these respiratory difficulties are lessened, although not eliminated.

## FOLLOW UP

Recent information on these patients was obtained in various ways. The majority were circularized by questionnaire; others were seen on recall to the outpatient clinic, while others, the most recent, were still attending the clinic. In all, out of a total of seventy-four, fifty-eight patients were contacted; three of these were in hospital; two were waiting further surgical procedures; one was recovering from a severe respiratory infection; and twelve had been operated on within the last three months of 1945, and were still attending clinic. There were forty-seven replies to the questionnaire. It was quite obvious that they did not magnify their good health. Possibly due to the pension angle, there was more pessimism displayed than was warranted by a check examination on a few of them. There were, in addition, five who had returned to clinic during 1945, and who reported themselves as well, free of cough, and sputum, and working full time.

In summarizing the results in fifty-two patients, their general health was reported to be, good in sixteen, fair in thirty-one, and poor in five. Of those in poor health: one had hemoptysis recurring from a small residual area of bronchiectasis; one had had a bilaterial involvement with removal of one lower lobe only; one had empyema and a nonexpanded right upper lobe (referred to under complications); one had several acute respiratory infections and was in hospital at the time; one had a small amount of intercostal neuritis. He was seen in clinic in January, 1946. He was in good health.

With regard to cough and sputum, nine reported no cough; twelve reported no sputum; twenty reported slight cough and sputum; twenty reported an appreciable amount of both cough and sputum.

Of those having definite cough and sputum, the majority reported a marked lessening following operation, with a few unchanged.

*Activity.*—Twenty-one of the fifty-two patients reported as doing full-time work; eleven of the fifty-two patients reported as doing part time work; thirteen of the fifty-two patients reported as doing no work at all. The majority of these thirteen had been operated on during the last six months, while another three of them were in hospital, two waiting further surgical treatment. Seven patients were at school.

## SUMMARY

1. A series of eighty lobectomies for bronchiectasis is reviewed as to: site, previous history, present history and findings, preoperative preparation, and operative technique.

2. Complications were few, and were as follows: empyema, seven; bronchopleural fistula, one; pneumonia, two; thrombophlebitis, one.

3. There was one death; a mortality of 1.25 per cent.

4. Follow-up reports in fifty cases showed: good or fair general health, 90 per cent; slight cough and sputum or none, in 60 per cent; working full or part time or at school, in 74 per cent.

# PNEUMOPYOPERICARDIUM

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PNEUMOPERICARDIUM is a rare condition. It is still more uncommon if this pneumopericardium becomes infected. The condition then turns into pneumopyopericardium. The outlook, once the diagnosis is made, is exceedingly grave. Patients with cases of traumatic origin are more likely to recover. In the majority of instances pneumopyopericardium is a terminal complication of a serious disease, and then the result is usually fatal.

## HISTORICAL

Galen is said to have removed a portion of the sternum and anterior wall of the pericardium in a soldier with a neglected chest wound. Surgical intervention is said to have cured the suppurative pericarditis. (Quoted by Winslow and Shipley.) Romero, in 1819, drained a serous pericarditis between the fifth and sixth ribs. Larrey, ten years later, in a stab wound of a soldier, suggested the xiphocostal approach to the pericardium. Laennec, in his writings, mentioned the value of the tympanitic sound at the superior portion of the heart to denote the presence of air in the pericardium. However, such eminent diagnosticians as Skoda, the discoverer of percussion and auscultation, and Schroetter (1898) his successor at the Vienna City Hospital, never saw a case of pneumopericardium in well over thirty-five years of experience. Bricheteau observed hemopneumopericardium in 1844 and in the same year Hilsmann reported curing a patient with pyopericardium. von Langenbeck (1860) performed pericardiotomy successfully, and Stokes collected three reported cases in 1855. Rosenstein in 1881 established surgical intervention as the method of choice in treating suppurative pericarditis. In 1885 Malle evacuated a hemopericardium through an opening made in the sternum and Bexman in 1891 performed the same procedure for a pyopericardium. James in 1904 reported on thirty-seven cases of pneumopericardium and mentioned the rarity of the disease. Rosler in 1918 collected seventy-three similar cases. Harvey B. Stone reported on a case of pericardiotomy for suppurative pericarditis following pneumonia performed on June 27, 1918, in Field Hospital No. 327 in France. More recently Winslow and Shipley (1935) reported on 118 patients with suppurative pericarditis of which twelve cases were due to gunshot and stab wounds. The remaining 106 cases were due to systemic infection. Winslow and Shipley operated upon 4 patients. Two of these recovered and two died.

## ETIOLOGY

The causes of pneumopericardium and its complicating pneumopyopericardium may be divided into three main headings: (1) trauma, (2) perfora-

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tion from neighboring organs, and (3) infection, or the spontaneous development of fluid, pus, and gas in the pericardium.

In taking up these three subdivisions separately one finds:

1. Trauma.
   - A. From without:
     - a. Punctured wounds, gunshot, and knife wounds. (Mueller, Thompson and Walsh, Bodenheimer)
   - B. From within:
     - a. Perforation of the esophagus into the pericardium by
       1. Swallowed knife or denture. (Thompson and Walsh, James and Imperatori)
       2. Swallowing of long strips of wire and metal. This is common in cattle and rare in man.
   - C. Fractured rib or sternum tearing the pericardium.
   - D. Spontaneous rupture of the bronchus into the pericardium by violent vomiting (Dufour and Barouk) or by strenuous bodily exercise and exertion (Ljungdahl) and by blast injury.
   - E. Artificial
     - a. Accidental
       1. Tuberculous pericardium mistaken for a tuberculous pleurisy and a pneumopericardium instead of a pneumothorax was induced (Rigler, Saupe)
       2. A hemopericardium was aspirated and air had been allowed to enter at time of pericardicentesis. A contaminated hemopneumopericardium resulted which grew *Staphylococcus aureus* on culture. (Harken, personal communication. Case seen during army service.)
     - b. Intentional. Aspiration of pericarditis with effusion and replacement with air. (Oppenheimer)
2. Perforation of inflammatory or suppurative foci into the pericardium from neighboring organs and structures, and vice versa.
   - A. Tuberculosis.
     - a. Lung cavity into the pericardium. (Laub, Langer, Poirier)
     - b. Caseous tuberculous lymph node behind the bifurcation of the trachea becoming adherent to the esophagus. This caused a traction diverticulum of the esophagus which broke through, causing a sinus from the esophagus through the lymph node into the pericardium. Two somewhat similar cases are reported. (Leys and Wallace, Zwilling)
     - c. Tuberculous lymph node breaking into the pericardium and then into a bronchus or the lung. Four such cases are reported by James.
   - B. Infection and suppuration.
     - a. Perforation of an empyema cavity which had been surgically drained, into the pericardium; and the perforation of a lung abscess or lung gangrene into the pericardium. (Jobin)

b. Perforation of pyopneumothorax into the pericardium. (Eisenlohr, Sievers)
c. Perforation of a liver abscess into the subdiaphragmatic space then into the stomach and finally into the pericardium. (Graves quoted by Müller)
d. Mediastino-pericarditis perforation. (Mayer)
e. Perforation of peptic ulcers into the pericardium. (Salmony, Saexinger, Moizard, Parisot)

3. Systemic infection causing suppurative pericarditis.
   A. Secondary to pneumonia, pleurisy, and Ludwig's angina.
   B. Spontaneous development of gas in the pericardium due to infection is extremely rare but is reported. *Bacillus welchii rarely* leads to a pneumopyopericardium. Ringler reported five cases of which one recovered. Harken saw a case of pneumopyopericardium in the armed service in which the organism was the *B. welchii*. It was penicillin sensitive and the patient recovered after aspiration and penicillin instillation. (Personal communication)
4. Perforation of malignant tumors into the pericardium.
   A. Gastric carcinoma. (James)
   B. Esophagus carcinoma. (James, Chambers, and Tütel)
   C. Bronchus carcinoma.
5. Perforation of primary suppurative pericarditis.
   A. Into cavities containing air. (Romberg, MacDovel quoted by Laub)
   B. Suppurative pericarditis perforating externally. (Müller)

### SYMPTOMS

The symptoms of pneumopericardium and pneumopyopericardium, when due to perforation, are the sudden onset of precordial pain. The patients become dyspneic and cyanotic. Frequently they faint. They may also complain of acute upper abdominal pain. Swelling in the precordial region may occur but is rare. Occasionally the patient complains of peculiar sensations and is conscious of peculiar sounds in the region of the heart noticed with each heart beat.

### PHYSICAL SIGNS

The area of cardiac dullness suddenly disappears and is replaced by an area of hyperresonance. The percussion note is deep and sonorous and almost tympanitic. The area of tympany may shift with the change in position of the patient.

On inspection, especially in children and young adults, there may be bulging in the heart region. The patients all have fever and a rapid pulse. The pericardium usually is enlarged. There is venous stasis throughout the body, as the heart has difficulty in filling due to compression. The heart itself is usually pushed forward against the chest wall. This must be kept in mind when performing a paracentesis.

On auscultation, very definite and characteristic sounds are heard. A metallic sounding phenomenon is present with a splashing and tinkling sound heard at the apex of the heart synchronous with the heart beat. Patients themselves are frequently conscious of this phenomenon. The sound is that of a gurgling brook or the bursting of bubbles, or the splashing of water on the wheel of a water mill.

### DIAGNOSIS

The x-ray films are distinctive and offer the greatest help in diagnosis. The x-ray exposure must be short to give a sharp outline. There often is a double shadow, the inner heart shadow and an outer one, either that of fluid or air or both in the pericardium. (Schulze, Schwaer, Amelung.)

Aspiration of the pericardium is of great diagnostic value. Culture of the aspirated fluid is important. Harken, in a personal communication, has drawn attention to the importance of culture in making a diagnosis. He has seen a patient in whom a diagnostic aspiration of what was believed to be a pericardicentesis for suppurative pericarditis revealed pus which on culture showed mixed organisms. At surgical pericardiotomy a mistake in diagnosis was apparent. An extrapericardial abscess was found that had dissected around the pericardium to an extent that it had been mistaken for a suppurative pericarditis. The x-ray and fluoroscopic appearance was classical. At operation the pericardium was closed and the mediastinal empyema was drained from behind without entering the pleural space. The patient did well. Harken states that the presence of mixed organisms should have made one suspicious of an extrapericardial abscess. A short time later Harken saw a similar case and in this instance injected lipiodol into the pericardial sac. He was thereby able to show that the pericardium was not involved in the abscess.

Pericarditis is frequently overlooked in its insidious onset during a grave disease. Its presence must always be kept in mind and must be ruled out.

In the differential diagnosis one must rule out mediastinal pleuritis, a dilated esophagus, a paravertebral abscess and an aneurysm of the abdominal aorta. All of these conditions may give similar x-ray films.

Pneumomediastinum may be a complication of surgical emphysema, especially in chest wounds, and must also be kept in mind.

### OPERATIVE TECHNIQUE

Anesthesia for pericardiotomy may be either local or general. If general anesthesia is chosen the introduction of an intratracheal tube is of value.

A curved incision is made just to the left of the sternum from the level of the second rib downward and then outward onto the left costal arch. The fourth, fifth, and sixth and sometimes the third costal cartilages are resected. The internal mammary vessels are ligated and divided. If necessary, some of the lateral border of the sternum is resected with rongeur. Every effort is made to avoid injury of the pleura. It is wiped away if not too adherent by inflammatory adhesions. The pericardium must be well exposed and free of pleura.

The pericardium is then incised longitudinally in its long axis for good drainage, all the way down to its most dependent portion. The pericardial sac is explored with the finger and adhesions are broken with great gentleness. The pericardial sac is then irrigated gently and 25,000 to 40,000 units of penicillin in about an ounce of saline are instilled. No irritating fluid should be used for irrigation. Beck has shown in the dog that Dakin's solution can cause adhesive pericarditis. If the pericardial sac is irrigated, one should be sure to have free exit for the fluid. The wound is left open and if the suppuration subsides and the wound is granulating, secondary closure of the skin over the heart is performed.

The former trans-sternal and xiphocostal approaches to the pericardium are not as efficient as the technique above described.

*Complications.*—One must watch for a possible associated empyema and suppuration in neighboring organs. A serious complication and one that must be carefully observed is that of constrictive pericarditis (Pick's Disease). Fortunately, it is not common as a postoperative complication.

## PROGNOSIS

The prognosis is always grave. In suppurative pericarditis, 70 per cent cures are possible. In pneumopyopericarditis the outlook is not so good. The chief factors influencing the prognosis are the time of operation, the type of organism involved, and the original condition of which the pyopericardium or pneumopyopericardium is the complication. Also whether there are other foci of suppuration elsewhere in the body.

The immediate and late prognosis is serious. Immediate drainage offers the only hope, with the help of chemotherapy. In the traumatic group of cases the prognosis is somewhat better. In all others it is extremely poor from the very beginning.

Müller reported three cures in pneumopyopericardium. Two were traumatic cases, and one was a perforation of an empyema into the pericardium. The prognosis in pericardiotomy for suppurative pericarditis is much better than in pneumopyopericardium. Winslow and Shipley reported on 118 patients with suppurative pericarditis with ten of their own, making 128 in all. Seventy-one or 55.47 per cent recovered and fifty-six or 43.65 per cent died. In one case the result was not known. Necessarily the prognosis must be modified by the primary disease involved.

## CASE REPORT

On March 3, 1945, a Russian Displaced Personnel girl, 23 years of age, was admitted to our evacuation hospital ten days after having been injured by a fragment of a hand grenade.

She was desperately ill and very toxic. There was deep jaundice. The temperature was 102.4° F., pulse 140, blood pressure 110/62. Hematocrit was 17.5 per cent, hemoglobin 6 Gm., total protein 6.5 Gm. White blood cells 53,000 with a high differential count.

She was immediately given blood transfusions. On physical examination the patient was dyspneic, cyanotic, and orthopneic. She was alert and rational. There was a wound of entrance over the third rib just to the left of the sternum and a smaller one in the left breast at about 9 o'clock near the periphery of the breast. From the larger wound, thin,

frothy pus was exuding. The left chest was dull on percussion posteriorly, and on auscultation there was bronchial breathing at both bases. On percussion the heart dullness was increased to the right and to the left and on auscultation over the heart there was a typical bubbling, tinkling, babbling, and swishing sound. The abdomen was distended and tympanitic. The liver was palpable. There was no edema over the sacrum or the lower extremities.

X-ray examination showed a typical pneumopericardium with a foreign body within the pericardium in the region of the great vessels. There was dense infiltration of the left lung field (Figs. 1 and 2).

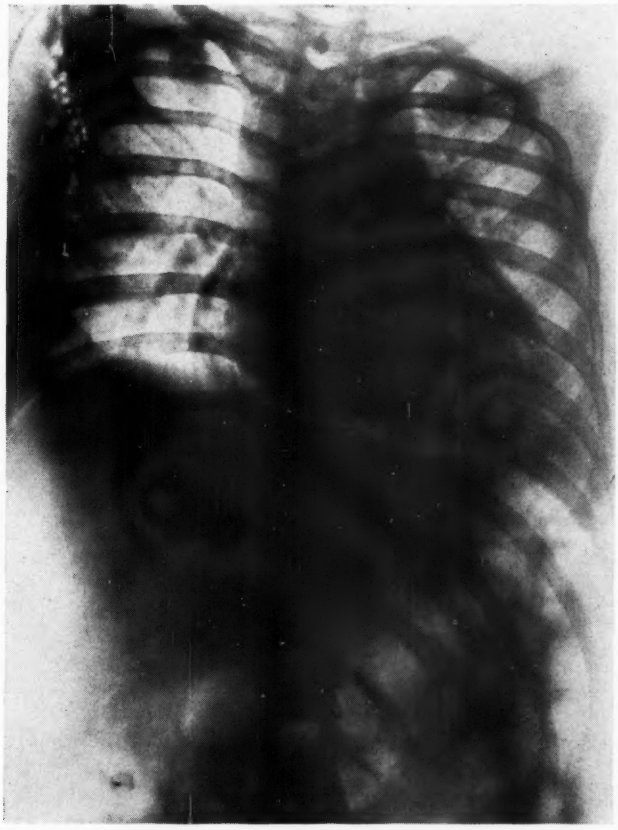


Fig. 1.—X-ray film showing pneumothorax with grenade fragment in pericardium.

After sufficient preparation with infusions and transfusions, pericardiotomy was decided on.

Operation was performed March 4, 1945. GOE endotracheal anesthesia was administered by Lt. Col. Max Frick. The incision was made from the wound of entrance along the left sternal border to the fifth interspace and then curved outward. A skin and muscle flap was dissected outward exposing the ribs and cartilages. The third, fourth, fifth, and sixth rib cartilages, with about an inch of the bony ribs were resected. The intercostal structures were ligated and resected. The internal mammary vessels were ligated, divided,

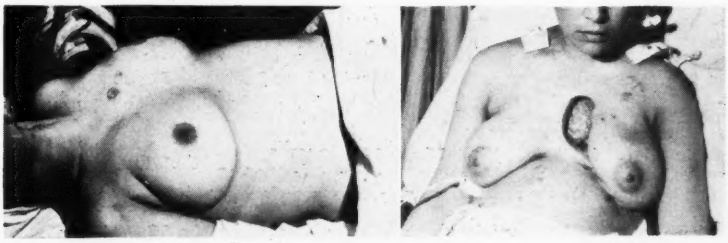
and removed. About three-fourths of an inch of the left border of the sternum was resected with a rongeur forceps. This exposed the pericardium with the wound of entrance in its upper portion. The pericardium was incised from the wound of entrance downward to the most dependent portion. The grenade fragment was lying slightly embedded on the pulmonary artery and was removed. The heart was covered with thick fibrin and bathed in frothy pus. The finger was introduced into the pericardium and behind the heart and many fine, fairly fresh adhesions were broken up. The pericardial sac was irrigated with saline and it was seen that the wall of the pulmonary artery was slightly injured where the missle had lodged. 40,0000 units of penicillin were instilled into the pericardial sac. The skin wound

Fig. 2.—Lateral x-ray film showing the same as Fig. 1.

to the left in the breast region was sutured. The remainder of the wound was left open and the parietal pericardium loosely stitched to the endothoracic fascia. The edges of the wound and the heart were covered with petrolatum gauze. The patient stood the surgical procedure nicely. (Fig. 3.)

*Postoperative Course.*—Penicillin, 40,000 units q. 4 hours and sulfadiazine Gm. 1 q. 4 hours, which had been started on admission, were continued. The smear from the pus from the pericardium showed many gram-negative and gram-positive diplococci. The serum bilirubin was 9.0 mg. per cent. The hematocrit reading on day of the operation was 30 per cent, hemoglobin, 10.2 Gm. and protein 5.8 Gm. The day after the operation 125 c.c. of fluid were aspirated from the left pleural cavity in the posterior axillary line. This aspiration was re-

peated daily and on the third postoperative day 225 c.c. were removed. Each time, 40,000 units of penicillin were instilled into the pleural cavity. Two hundred and fifty cubic centimeters of fresh whole blood in Alsever's solution were given daily for four postoperative days. On the fourth postoperative day there was an allergic reaction and the transfusions were temporarily stopped. Vitamins were given parenterally and per os. At every dressing the finger was passed around the heart and thick fibrin placques were removed. There always seemed to be some retention behind the heart in the pericardial sac. On the fifth postoperative day the patient developed some edema over the sacrum, buttocks and lower extremities. The venous pressure was 160 mm. $H_2O$. Two days later 2 c.c. salygran was given intravenously after consultation with the medical service. Also 250 c.c. of blood in Alsever's solution. There was again a reaction after the transfusion. A week after the operation the condition of the patient had greatly improved. Still very large amounts of fibrin placques were digitally removed from the pericardial sac. Six days later, or fourteen days after the operation, the patient was improving. There was still evidence of left pleuropulmonary pathology. There was, however, not much evidence of pleural exudate. The kidney output was satisfactory. The pus discharge from the pericardium was getting materially less. The pericardial sac was irrigated daily.



*A.* *B.*

**Fig. 3.**—*A*, patient on operating table showing wound of entrance in precordial region; *B*, patient one week after operation showing wound of pericardiotomy.

Due to the tactical situation, our hospital received orders to advance and the hospital was closed. Through the help of G 5 of the Army, the patient was transferred to another army hospital on the fourteenth day after operation in fairly satisfactory condition.

I was later informed by the Chief of the Surgical Service of the hospital that very shortly after transfer to the hospital the patient developed complete suppression of urine and in spite of everything that was tried she went into uremic coma and died five days later. A post mortem was performed.

The gross anatomical diagnosis of the autopsy was: (1) pericarditis, acute, marked, associated with (a) pyopericardium, (b) myocarditis with moderate right ventricular dilatation, and (c) acute mediastinitis; (2) bilateral hydrothorax; (3) pulmonary atelectasis, partial associated with pulmonary congestion; (4) acute cholecystitis, moderate; (5) pyelonephritis with pus in both pelves; (6) marked cystitis; (7) passive congestion of kidneys, liver and spleen; and (8) bilateral fibrous pleuritis.

## SUMMARY

1. Early diagnosis and recognition of pneumopericardium and pneumopyopericardium is of vital importance.

2. The physical signs and x-ray findings are very characteristic.

3. Suppurative pericarditis is too frequently overlooked, as proved by autopsies.

4. The prognosis in suppurative pericarditis is fairly good.

5. Traumatic etiology in pneumopyopericardium holds out a fair prognosis.

6. Pneumopyopericardium as a complication of some other grave disease has an extremely poor prognosis.

7. Early surgical intervention, aided by proper chemotherapy, holds out the only hope of cure.

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# MEDICAL TREATMENT OF ACUTE AND CHRONIC PULMONARY ABSCESSES

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## INTRODUCTION

MULTIPLE embolic abscesses, abscesses secondary to pulmonary neoplasms and primary bronchiectasis, together with tuberculous and mycotic infections, have been excluded from this study; but cases of acute and chronic suppurative bronchopneumonia and abscesses which precede, accompany, or follow bronchiectasis have been included.

In 1936, Allen and Blackman[2] collected 2,114 cases of pulmonary abscess from the American literature and found that the mortality in patients receiving medical treatment was 34.4 per cent and in those receiving both medical and surgical treatment was 34.2 per cent.

During the past ten years, remarkable progress has been made in the techniques of pulmonary surgery, and one would expect this to be reflected in a material reduction in mortality, yet among 2,166 cases collected from representative clinics since 1936, the gross mortality remains 34.2 per cent. Among 906 patients receiving medical treatment, the mortality was 34.7 per cent, while the mortality among 744 cases treated by surgical procedures was 32.7 per cent (Table I).

Tables II and III show a wide variation in mortality from clinic to clinic for both medical and surgical therapy. Neuhof and Touroff[32, 33] stand alone in reporting entirely satisfactory results with but four deaths in 152 cases, or a mortality of 2.6 per cent. This low mortality was obtained by operating on abscesses of less than six weeks' duration and presumably by excluding from this series abscesses designated by Neuhof and Thomas[31] as "acute suppurative bronchopneumonia."*

Speaking as an internist, it is my impression that the general practitioner and the internist, not the surgeon, are primarily responsible for the conditions which result in the death of one-third of the patients who develop primary pulmonary abscesses. The following analysis of our cases, supplemented by a study of the literature for the past ten years, is presented with the hope that the medical treatment of primary pulmonary abscess can be improved sufficiently to give a final mortality for the combined medical and surgical therapy of less than 10 per cent.

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Read (by title) at the Twenty-Sixth Annual Meeting of The American Association for Thoracic Surgery, Detroit, Mich., May 29, 30, and 31, 1946.

*The mortality in this type of pulmonary suppuration was 24.2 per cent of 120 cases and was primarily medical rather than postoperative. This type of suppurative pulmonary disease has been included in our series of abscesses, and it is my impression that it was included in the series presented in Tables II and III, with the possible exception of Arbuckle's group of forty-three cases treated by bronchoscopy with a mortality of 0 per cent.

TABLE I. TOTALS

| TREATMENT | TOTAL NUMBER | DIED | | WELL | | CHRONIC | |
|---|---|---|---|---|---|---|---|
| | | NUMBER | PER CENT | NUMBER | PER CENT | NUMBER | PER CENT |
| Medical | 906 | 314 | 34.7 | 284 | 31.3 | 308 | 34.0 |
| Surgical | 744 | 243 | 32.7 | 343 | 46.1 | 158 | 21.2 |

TABLE II. PULMONARY ABSCESS MORTALITY; SURGICAL TREATMENT

| AUTHOR | LOCATION | NUMBER | DIED | | WELL | | CHRONIC | |
|---|---|---|---|---|---|---|---|---|
| | | | NO. | % | NO. | % | NO. | % |
| Allen and Blackman*[2] | Detroit | 38 | 15 | 39.5 | 20 | 52.6 | 3 | 7.9 |
| Cutler and Gross[8] | Boston | 47 | 22 | 46.8 | 16 | 34.0 | 9 | 19.2 |
| Neuhof and Touroff[33] | New York | 152 | 4 | 2.6 | 148 | 97.4 | 0 | 0 |
| Shaw and Blackman[41] | Ann Arbor | 138 | 56 | 40.6 | 55 | 40.0 | 27 | 19.4 |
| Shaw[41] | Dallas | 33 | 5 | 15.2 | 19 | 57.6 | 9 | 27.2 |
| Lueth*[28] | Chicago | 23 | 16 | 69.6 | 7 | 30.4 | 0 | 0 |
| Rosenblatt[39] | New York | 21 | 12 | 57.2 | 5 | 23.8 | 4 | 19.0 |
| Jackson and Judd[18] | Philadelphia | 37 | 18 | 48.7 | 15 | 40.5 | 4 | 10.8 |
| D'Ingianni[9] | New Orleans | 141 | 64 | 45.4 | 4 | 2.8 | 73 | 51.8 |
| Overholt and Rumel[34] | Boston | 63 | 13 | 20.6 | 35 | 55.6 | 15 | 23.8 |
| Smith | Durham | 51 | 18 | 35.3 | 19 | 37.3 | 14 | 27.4 |
| Total | | 744 | 243 | 32.7 | 343 | 46.1 | 158 | 21.2 |

*Calculated from data given by the author.

TABLE III. PULMONARY ABSCESS MORTALITY; MEDICAL TREATMENT

| AUTHOR | LOCATION | NUMBER | DIED | | WELL | | CHRONIC | |
|---|---|---|---|---|---|---|---|---|
| | | | NO. | % | NO. | % | NO. | % |
| Allen and Blackman*[2] | Detroit | 55 | 14 | 25.5 | 30 | 54.5 | 11 | 20.0 |
| Cutler and Gross[8] | Boston | 36 | 8 | 22.2 | 20 | 55.6 | 8 | 22.2 |
| Shaw and Blackman[41] | Ann Arbor | 89 | 27 | 30.3 | 49 | 55.1 | 13 | 14.6 |
| Shaw[41] | Dallas | 16 | 2 | 12.5 | 11 | 68.8 | 3 | 18.7 |
| Lueth*[28] | Chicago | 73 | 18 | 24.7 | 45 | 61.6 | 10 | 13.7 |
| Rosenblatt[39] | New York | 72 | 34 | 47.2 | 4 | 5.6 | 34 | 47.2 |
| Jackson and Judd[18] | Philadelphia | 87 | 23 | 26.5 | 33 | 37.9 | 31 | 35.6 |
| Kline and Berger[21] | Cleveland | 57 | 26 | 45.6 | 31 | 54.0 | 0 | 0 |
| D'Ingianni[9] | New Orleans | 276 | 141 | 51.1 | 8 | 2.9 | 127 | 46.0 |
| Overholt and Rumel[34] | Boston | 18 | 10 | 55.5 | 5 | 27.8 | 3 | 16.7 |
| Arbuckle[3] | St. Louis | 43 | 0 | 0 | 19 | 44.2 | 24 | 55.8 |
| Smith | Durham | 84 | 11 | 13.1 | 29 | 34.5 | 44 | 52.4 |
| Total | | 906 | 314 | 34.7 | 284 | 31.3 | 308 | 34.0 |

*Calculated from data given by the author.

## MODE OF ONSET

A total of 135 cases of primary pulmonary abscess were admitted to Duke Hospital from 1940 to 1945 inclusive. The mode of onset is shown in Table IV. The number following operations was 37 or 27 per cent. This number has varied from a low of 15 per cent in Rosenblatt's ninety-three cases[39] to a high of 54 per cent in Cutler and Gross' eighty-three cases.[8] There is a general impression in the literature that the prognosis is better in postoperative abscesses than in the nonoperative type. In Cutler and Gross' series with 54 per cent postoperative cases, 36.1 per cent died, 43.4 per cent recovered, and 20.5 per cent remained chronic; but in Rosenblatt's series[39] with 15 per cent postoperative, there was a mortality of 49.5 per cent with only 9.7 per cent well and 40.8 per cent chronic. There were unquestionably factors other than "mode of onset" which determined the greater mortality in Rosenblatt's series.

TABLE IV. MODE OF ONSET

| MODE | NO. |
|---|---|
| Insidious | 67 |
| Pneumonic | 25 |
| Tonsillectomy | 14 |
| Extraction of teeth | 11 |
| Other operations | 12 |
| Foreign body | 6 |
| Total | 135 |

TABLE V. PROGNOSIS BY MODE OF ONSET

| MODE OF ONSET | NUMBER | DIED | | WELL | | CHRONIC | |
|---|---|---|---|---|---|---|---|
| | | NO. | % | NO. | % | NO. | % |
| Postoperative | 37 | 8 | 22.0 | 19 | 51.0 | 10 | 27.0 |
| Postpneumonic | 25 | 8 | 32.0 | 6 | 24.0 | 11 | 44.0 |
| Insidious | 67 | 11 | 16.0 | 21 | 31.0 | 35 | 53.0 |
| Foreign body | 6 | 2 | 33.3 | 2 | 33.3 | 2 | 33.3 |
| Total | 135 | 29 | 21.4 | 48 | 35.6 | 58 | 43.0 |

In Table V there is an analysis of the prognosis by mode of onset in our 135 cases. There are 51 per cent well in the postoperative group in contrast to 35.6 per cent for the group as a whole, but there was a 22 per cent mortality in the postoperative group and only 21.4 per cent for the entire group.

From this and other series it does seem that the postoperative group has a better chance to make a complete recovery than other groups. The improved prognosis may be related more to the shorter duration of the disease when treatment is started rather than to the mode of onset. In our cases the mean duration of the disease was 4.5 months for the entire group and only two months for the postoperative cases.

With the present almost universal treatment of postoperative febrile reactions with penicillin, the number of postoperative abscesses should be materially reduced.

### DURATION OF DISEASE

Nearly every writer on the subject of pulmonary abscess has emphasized the importance of early diagnosis and prompt treatment.[26] In Lord's series of 127 cases collected between 1909-1924, there were no spontaneous recoveries after nine weeks.[27] Among the 210 cases reported by King and Lord[20] from 1924-1932, there were thirty-four or 30.9 per cent medical cures in the acute cases of less than two months and only eleven or 11 per cent cures in the 100 cases of more than two months' duration. In the series of Flick and associates[11] of 121 cases, the recovery rate was 70 per cent when the disease was less than three months old. Jackson and Judd[18] obtained their best results with bronchoscopic treatment when the disease was of four to six weeks' duration.

In 1926, Miller and Lambert[30] selected three months' duration as the ideal time for the open drainage of pulmonary abscesses. Before this time the patients have not developed their maximum immunity to the infection, and after three months the progressive fibrosis and dilatation of veins increase the hazards of the operation, both from postoperative hemorrhages and from thrombosis and

embolism. With the introduction of sulfonamides and penicillin the spreading infection about the abscess can be controlled and operation can and should be performed much sooner.

Neuhof and Touroff[33] insist that open operation for the drainage of isolated abscesses should be done before the end of the sixth week, and they have treated 152 cases of this type with a mortality of only 2.6 per cent. Lindskog[24] obtained a mortality of 4.5 per cent in twenty-two cases of less than two months' duration, and Overholt and associates[34] a mortality of 6 per cent in thirty-five simple abscesses of less than six weeks' duration.

In 1938, Rives, Major, and Romano[38] analyzed the cause of death in 100 fatal cases of pulmonary abscess and found a death rate of 57 per cent in the acute cases admitted to the hospital during the first four weeks of the disease, only 15 per cent for those admitted between the fourth and eighth weeks and 9 per cent between the second and third months. Since these cases were studied before the introduction of sulfonamides and penicillin, we may assume that they represent the initial high mortality from the disease itself which Miller and Lambert sought to avoid by delaying the operation until the second or third month. Even with the aid of sulfonamides and penicillin, Neuhof and Touroff[33] have advanced the time of operation where they are finding a more acute type of abscess which they call "hyperacute." There have been three deaths (7.3 per cent) in forty-one cases of this "hyperacute" type and only one in the remaining 111 cases of acute single abscesses.

In Table VI is presented an analysis of our 135 cases classified on the basis of the duration of the disease at the time of admission to the hospital. There were thirty-eight cases of less than four weeks' duration. Two of these patients were treated surgically and both died. Of the thirty-six treated medically, five died (14 per cent), nineteen recovered (53 per cent) and twelve improved (33 per cent) but were transferred to surgery for operation. There were no surgical deaths in the five patients operated on between the fifth and twelfth weeks of the disease. Among the twenty-four patients treated medically, one died, six recovered and seventeen were transferred to surgery for operation. Apparently the optimal time for medical treatment is during the first four weeks of the disease, and this must be calculated from the onset of the first febrile reaction and not from the time the first purulent sputum is produced. After the third month of the disease, medical treatment cured only four (5.3 per cent) of the seventy-five cases, while five (6.7 per cent) died and sixty-six (88 per cent) remained chronic.

TABLE VI. PROGNOSIS BY DURATION; 135 CASES

| | LESS THAN 2 WEEKS | | | 2 TO 4 WEEKS | | | 5 WEEKS TO 3 MONTHS | | | 3 TO 6 MONTHS | | | 6 MONTHS TO 1 YEAR | | | 1 YEAR TO 10 YEARS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TYPE TREATMENT | DIED | WELL | CHRONIC | DIED | WELL | CHRONIC | DIED | WELL | CHRONIC | DIED | WELL | CHRONIC | DIED | WELL | CHRONIC | DIED | WELL | CHRONIC |
| Medical | 3 | 10 | 3 | 2 | 9 | 9 | 1 | 6 | 17 | 1 | 1 | 31 | 3 | 3 | 20 | 1 | 0 | 15 |
| Surgical | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 3 | 9 | 6 | 4 | 5 | 6 | 3 | 2 | 5 | 4 |

ETIOLOGY

The primary damage to the lung may be chemical from the irritative oils of an aspirated peanut or the effect of gastric secretions aspirated from vomitus, or mechanical from pulmonary thrombosis or infarction or the aspiration of a solid foreign body. In these four instances the infection in the lung is secondary and the prognosis depends to a considerable degree upon the type of secondary invader. Embolic abscesses usually are multiple and a part of a generalized pyemia, but in some instances single isolated abscesses result from infected emboli, particularly from the pelvic veins, and these abscesses cannot be distinguished clinically from the ordinary aspiration type.

A large majority of pulmonary abscesses result from the aspiration of infected material from the patient's own mouth or upper respiratory tract. These aspiration abscesses can be divided into (1) the pyogenic type and (2) the fusospirochetal type.

BACTERIOLOGY

In this series of 135 cases of primary pulmonary abscess, thirty-five were classified as pyogenic and 100 as fusospirochetal (Tables VII and VIII).

Aerobic cultures alone are of very little value in establishing the true cause of an abscess. The aerobic cultures from ten patients with pulmonary tuberculosis, ten patients with pulmonary neoplasm and ten with fungus infections of the lungs were compared. Varying combinations of staphylococci, alpha streptococcus, *Micrococcus catarrhalis* and *Micrococcus pharyngis siccus* were found in all thirty cases. Tubercle bacilli must be eliminated by repeated examinations after concentration of the sputum, actinomycosis by direct examination for sulfur granules, and the yeastlike fungi by cultures on Sabouraud's medium. Every patient with an abscess who is over 40 years of age should be suspected of having a pulmonary neoplasm even when the bronchoscopic examination is negative. Fusiform bacilli should be sought for in smears stained with gentian violet. It is important for the technician to realize that the large fusiform bacillus so characteristic of Vincent's angina usually is absent in cases of pulmonary abscess. One should look for very small, pointed, fusiform bacilli which are practically always present in the fusospirochetal type of abscess. These small fusiform bacilli may be accompanied by the thicker spirochetes *Borrelia buccale* and *B. vincenti.* If fusiform bacilli are present and no spirochetes are seen in the gentian violet preparation, additional examinations should be made with the Fontana stain or the dark-field apparatus to demonstrate the smaller type of spirochetes, *Treponema macrodentium* and *Treponema microdentium,* which are characteristic of the fusospirochetal type of infection. The fusiform bacilli and spirochetes are always accompanied by vibrios, gram-negative bacilli, including *Bacterium melaninogenicum,* and anaerobic gram-positive cocci. *Staphylococcus albus* and *aureus* may or may not be present.

If one has eliminated tuberculosis, neoplasm, fungus infection, and fusospirochetal organisms, and the aerobic cultures contain large numbers of (1) *Staph. aureus,* (2) *Pseudomonas pyocyanea (Bacillus pyocyanea),* (3) colon

TABLE VII. PYOGENIC ABSCESS

| NUMBER | SPUTUM | STAPHYLOCOCCUS AUREUS | FRIEDLANDER'S BACILLUS | PYOCYANEUS | SYMBIOTIC ORGANISMS | PEANUT | SPIROCHETES | FUSIFORM BACILLI | MIXED ORGANISMS |
|---|---|---|---|---|---|---|---|---|---|
| 24 | Sputum not foul | Pos. | -- | -- | -- | -- | Neg. | Neg. | Neg. |
| 1 | Sputum not foul | Neg. | Pos. | -- | -- | -- | Neg. | Neg. | Neg. |
| 1 | Sputum not foul | Pos. | Pos. | Neg. | -- | -- | Neg. | Neg. | Neg. |
| 1 | Sputum not foul | Neg. | Neg. | Neg. | Pos. | -- | Neg. | Neg. | Neg. |
| 2 | Sputum not foul | -- | -- | -- | -- | Pos. | Neg. | Neg. | Neg. |
| 5 | Empyema not foul | Pos. | -- | -- | -- | -- | Neg. | Neg. | Neg. |
| 1 | Empyema foul | Neg. | Neg. | Pos. | -- | -- | Neg. | Neg. | Neg. |
| Total 35 | | | | | | | | | |

TABLE VIII. FUSOSPIROCHETAL ABSCESS

| NUMBER | SPUTUM | SPIROCHETES | FUSIFORM BACILLI | STAPHYLOCOCCUS AUREUS | MIXED ORGANISMS |
|---|---|---|---|---|---|
| 53 | Sputum foul | Positive | Positive | Negative | Positive |
| 6 | Sputum foul | Positive | Positive | Positive | Positive |
| 7 | Sputum foul | Negative | Positive | Negative | Positive |
| 1 | Sputum foul | Negative | Positive | Positive | Positive |
| 4 | Empyema foul | Positive | Positive | Negative | Positive |
| 3 | Empyema foul | No examination | -------- | -------- | -------- |
| 10 | Sputum foul | By history | No examination | -------- | -------- |
| 5 | Sputum not foul | Positive | Positive | Negative | Positive |
| 5 | Sputum not foul | Negative | Positive | Negative | Positive |
| 6 | Diagnosis by operation or necropsy | | | | |
| Total 100 | | | | | |

bacillus, (4) *Proteus* or (5) gas gangrene organisms, we can conclude that the patient has a pyogenic abscess.

The pioneer studies of Kline[21] in Cleveland, Pilot and Davis[35] in Chicago, and Smith[42, 45] in the Adirondacks between 1920 and 1930 established the frequency and importance of the fusospirochetal type of organism as the cause of pulmonary abscess. Kline[21] and Smith[43] found the fusospirochetal type of infection in 90 per cent of abscesses in adults but in only 50 per cent of abscesses in children. This group of fusospirochetal and accompanying anaerobic organisms gives the characteristic fetid odor to the sputum of abscessed patients although occasionally the foul odor is caused by (1) colon bacilli, (2) *Proteus*, (3) *Pseudomonas pyocyanea*, or (4) gas gangrene organisms.

The multiplicity of organisms present in the fusospirochetal type of abscess has resulted in considerable skepticism on the part of the medical profession in accepting this as a specific type of infection. There is no question that this group of organisms as a unit can reproduce in experimental animals the typical clinical and pathologic picture of primary pulmonary abscess. Experimental lesions of this type have been produced by Kline,[22] Smith,[44, 47] Crowe and Scarff,[7] Allen,[1] Hedblom, Joannides, and Rosenthal,[16] Harkavy,[15] Van Allen, Adams, and Hrdina,[52] Herrmann and Cutler,[17] Lambert and Weeks,[23] Bethune,[5] Hamilton,[14] Longacre and Herrmann,[25] and Weiss and Shevky.[55]

Smith[46] isolated the various components of this mixture of organisms in pure culture and found that no one of the organisms alone would produce an abscess in an experimental animal. However, a mixture made from pure cultures of a spirochete, a small fusiform bacillus, a vibrio and an anaerobic gram-positive coccus could reproduce the typical disease. Smith's work has been confirmed in all details by Proske[36] and Proske and Sayers.[37] If one will accept the principle of symbiosis, then Koch's postulates have been fulfilled in this disease which we call for convenience "fusospirochetal" although recognizing that the vibrios and anaerobic cocci are an essential part of the symbiosis. We agree with Cohen[6] and Weiss and Mercado[54] that *Bact. melaninogenicum* and various types of anaerobic streptococci are constantly present in clinical cases of this type of abscess. None of the organisms studied by Cohen[6] and Weiss and Mercado[54] were pathogenic for animals, and since Smith[46] and Proske[36, 37] were able to reproduce the disease without including *Bact. melaninogenicum*, we consider it an associated but not an essential part of the symbiosis.

In examining sputum from a patient for fusospirochetal organisms, it is imperative that the examination be confined to the purulent portions and that the contaminating saliva which not infrequently contains fusiform bacilli and spirochetes from the mouth be avoided. It is most unfortunate that physicians usually do not suspect the presence of a pulmonary abscess until the sputum becomes fetid. In the incipient pneumonic stage of a fusospirochetal abscess the sputum is never fetid, and yet it is most important that the medical man suspect the diagnosis, demonstrate the fusospirochetal organism, and give appropriate treatment before there is a large destructive lesion in the lung.

## PATHOLOGY

The fusospirochetal type of infection results in gangrene of the lung, and Kline[21] of Cleveland, has taught for years that the term "abscess" be confined to the lesion caused by the pyogenic organism. The same idea is implied in Neuhof and Touroff's insistence that abscesses of this type be designated "putrid" abscesses.[33] We prefer the well-known name "abscess" but modified by a descriptive term to indicate the type of infection, for example, fusospirochetal abscess, staphylococcus abscess, Friedlander's bacillus abscess, etc. The fusospirochetal type of infection results most frequently in a single isolated peripheral abscess, while the pyogenic organisms are more often associated with multiple small abscesses; but there are many individual exceptions to this generalization, and the final answer must be obtained from the laboratory. The prognosis undoubtedly is better in the single isolated abscess than in the multiple type of abscess. An attempt to classify abscesses as "simple" and "complicated" has been made by several students of the disease.[34] The age of the lesion is of importance in this connection because the original primary fusospirochetal abscess tends to develop associated abscesses and bronchiectasis in the surrounding zone of inflammation as the disease becomes chronic and, therefore, changes from a simple into a complicated abscess.

### THERAPY OF ACUTE PULMONARY ABSCESS

Rest in bed is as essential in pulmonary abscess as in pulmonary tuberculosis. The patient's general resistance should be supported by a good diet and supplementary vitamin therapy. The ideal time for medical treatment is in the first week of the disease when there is still an efficient circulation in the area of the infection and before there is any extensive necrosis of the pulmonary tissues. Once the abscess has developed, drainage is an absolutely essential part of the treatment. Medical drainage is accomplished by posture. Upper lobe lesions usually are drained more effectively by having the patient rotate right side, left side, back, and chest at fifteen-minute intervals while awake. Lower lobe lesions drain best by lowering the head and chest over the edge of the bed or by means of a specially constructed table. Drainage frequently is improved by periodic bronchoscopic aspirations, and at least one bronchoscopic examination should be made of every patient over 30 years of age to help rule out pulmonary neoplasm.

### BRONCHOSCOPIC TREATMENT

In Allen and Blackman's series of 2,114 patients, 650 were treated by bronchoscopy. Of these, 61 per cent recovered, 6.5 per cent died and 32.5 per cent remained chronic. In the group of 121 cases treated by Flick, and associates,[11] 54 per cent were cured but the recovery rate was 70 per cent in those who had had the disease less than three months. Among Lueth's thirty-seven patients[28] twenty-four recovered, eight died, and five remained chronic, while in Arbuckle's forty-three patients[3] nineteen recovered, four improved, and twenty failed to improve.

There are two stages in the development of pulmonary abscess in which bronchoscopy is very effective. In cases of postoperative atelectasis, bronchoscopic aspiration of plugs of mucus or blood from the bronchi frequently aborts the disease. Bronchoscopy offers little, if any, assistance in the typical pneumonic stage of the disease where there is very little sputum. When the abscess is once fully developed, bronchoscopic treatment again becomes effective in keeping patent the drainage tract from the abscess. After the disease has progressed for more than three months, bronchoscopic aspirations give somewhat better results than postural drainage alone but rarely cure the patient.

### ARSENICAL THERAPY

Of Allen and Blackman's 2,114 patients,[2] sixty-eight were treated with arsenicals with 47 per cent recoveries; 8.8 per cent died, and 44.2 per cent remained chronic. Fisher and Finney[10] report that some early cases improve with neoarsphenamine therapy. Joannides[19] reports good results in early cases and Lueth[28] obtained excellent results in ten cases of early abscess with neoarsphenamine. On the other hand, Sweet,[50] Rosenblatt,[39] Cutler and Gross,[8] Freedman[13] and Rives, Major, and Romano[38] state that arsenical therapy was a complete failure.

The best results with the arsenicals have been reported by Kline and Berger[21] with 68 per cent recoveries. Smith[43] has reported thirty acute cases with 60 per cent cured.

This sharp difference of opinion as to the value of arsenical therapy can be explained in part by the type of case treated in the different series. Practically all of the good results have been obtained in the first eight weeks of the disease and the best results in the first ten days when the infection was still in the pneumonic stage with the circulation intact and before any appreciable necrosis of the lungs had occurred. Arsenicals are palliative only in cases of more than three months' duration.

### SULFONAMIDE THERAPY

Sulfonamides have a bacteriostatic effect on the gram-positive organisms but no effect on the spirochetes and fusiform bacilli. One would expect a sharp difference in results between pyogenic abscesses and fusospirochetal abscesses. Table IX shows our results in ten cases of pyogenic abscess and twenty-four cases of fusospirochetal abscess. There was only one death and six recoveries in the pyogenic group, while there were three deaths and only two recoveries in the fusospirochetal group, although in most instances the sulfonamides were given within twenty-four to forty-eight hours after the appearance of the first febrile reaction. In D'Ingianni's series[9] there was a death rate of 58.6 per cent in patients treated with sulfonamides as compared with 49.1 per cent for the entire group; on the other hand, the patients receiving arsenicals or bismuth had a death rate of only 34.2 per cent.

In our experience, sulfonamide therapy for the fusospirochetal type of infection has been harmful in an indirect manner. Patients in the early pneumonic stage of the disease usually show marked temporary improvement which encourages continuation of the therapy; then later they develop necrotic abscesses which will no longer respond either to sulfonamides, arsenicals, or penicillin, and require surgical treatment.

TABLE IX. SULFONAMIDE THERAPY

| TYPE ABSCESS | NUMBER | DIED | WELL | CHRONIC | FOUL SPUTUM |
|---|---|---|---|---|---|
| Pyogenic | 10 | 1 | 6 | 3 | 0 |
| Fusospirochetal | 24 | 3 | 2 | 19 | 16 |

TABLE X. PENICILLIN THERAPY

| TYPE ABSCESS | NUMBER | DIED | WELL | CHRONIC |
|---|---|---|---|---|
| Multiple metastatic | 7 | 3 | 4 | 0 |
| Pyogenic | 3 | 0 | 2 | 1 |
| Putrid or mixed | 50 | 7 | 32 | 11 |
| Total | 60 | 10 (16.7%) | 38 (63.3%) | 12 (20%) |

### PENICILLIN TREATMENT

Theoretically, penicillin therapy should be ideal for both the pyogenic abscess caused by gram-positive cocci and the fusospirochetal type of abscess, because penicillin is more effective against gram-positive cocci than sulfonamides and is quite as efficient as arsenicals in eliminating spirochetes. Smyth and Billingslea[48] collected thirty-one cases of pulmonary abscess from the literature

and added four of their own. Meleney, Friedman, and Harvey[29] treated one case with penicillin in which there was a *Clostridium welchii* infection. Stivelman and Kavee[49] report the recovery of five of six acute putrid abscesses following penicillin therapy. Nineteen of the patients in our series were treated with penicillin. Table X shows the results of penicillin in these sixty collected cases. The results are very encouraging. For the early incipient stage of the infection, penicillin is certainly the drug of choice (Figs. 1, 2, and 3), but it is not effective in the chronic cases although the patients may improve to a point where they are better surgical risks.

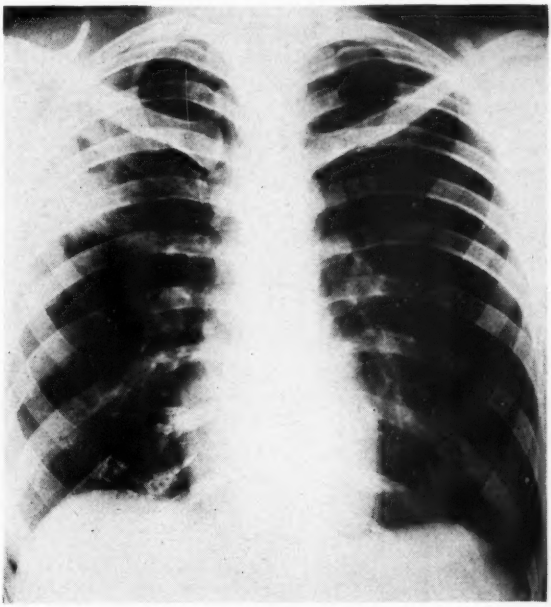

Fig. 1.—The x-ray film shows a pneumonic process in the outer two-thirds of the right upper lobe which contains a large thin-walled cavity with fluid level. The patient had putrid sputum which contained fusiform bacilli, spirochetes, vibrios and cocci. Penicillin therapy in doses of 20,000 units every three hours was started during the second week of the disease, dating the onset from the first appearance of fever.

Recent reports[4, 40, 53] of penicillin inhalations indicate that patients with chronic abscess and bronchiectasis obtain striking temporary improvement which makes them better operative risks, but the chronic type of the disease cannot be cured by this treatment.

### MEDICAL TREATMENT OF CHRONIC PULMONARY ABSCESS

The ineffectiveness of medical treatment in chronic pulmonary abscess has already been discussed in the section on the duration of the disease. There is an occasional case in which operation is contraindicated or where operation is refused by the patient and the medical man must attempt treatment. A case of this type is illustrated in the following report.

## CASE REPORT

CASE 1.—Mrs. G. F. L., aged 20, had her tonsils removed July 13, 1942, under a general anesthetic. Some bleeding occurred at the time of the operation, and the patient vomited dark blood the next day. The patient was discharged three days after tonsillectomy. A week later, while attending a picnic, she was caught in a summer shower and developed a cough. This dry cough became progressively worse during the next two weeks, but the patient continued her work in a hat shop for another week, when the development of fever and malaise necessitated confinement to bed. She began to notice pain in the right side about this time. After three days in bed she was admitted to a local hospital and treated with sulfonamides for twelve days. The cough was now productive of a very small amount of purulent sputum, and films of her chest showed a pneumonic process in the center of the right lung field (Fig. 4). Her general condition improved while she was in the hospital, but all symptoms returned with greater intensity after her return home. Vitamins, one blood transfusion, and local applications of heat to the right side did not relieve her symptoms.

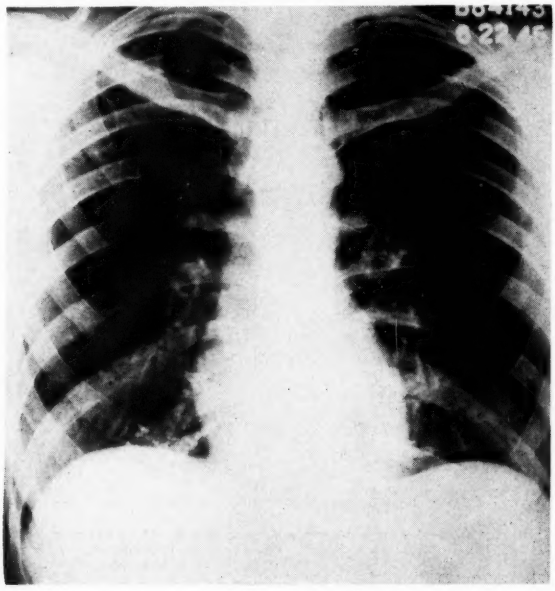

Fig. 2.—The x-ray film is of the same patient as shown in Fig. 1, four weeks after penicillin treatment was started. The parenchymal involvement has been absorbed, but the thin-walled cavity can still be seen in the right upper lobe. The patient was afebrile and there was no sputum at this time.

On Oct. 2, 1942, about eleven weeks after the tonsillectomy, a rib was resected and drainage tubes inserted by a local surgeon. Very little material drained through the tubes; her cough became paroxysmal and produced ounces of foul, purulent sputum. She developed high spiking temperature accompanied by nausea.

About Nov. 2, 1942, the pulmonary abscess was drained under local anesthesia, through the original thoracotomy wound. She remained critically ill for the next six weeks and then began to improve. Postural drainage and general supportive treatment, including twelve blood transfusions, were used between September 3 and January 17.

The patient was discharged from the hospital April 15, approximately six months after the first operation on her lung. The sinus in the chest was discharging small amounts of

material and her cough, although no longer paroxysmal in character, still produced about three ounces of purulent sputum daily. She continued to improve during the summer of 1943 and the sinus in the chest wall closed about the last of August, but the productive cough persisted. In September, 1943, she had three severe hemorrhages and was again hospitalized for fifteen days.

She remained at home from September, 1943, until she came to Duke Hospital April 4, 1944, twenty months after tonsillectomy. During the interval her general condition gradually improved, but she continued producing two to three ounces of foul, purulent sputum which occasionally contained blood. She had been ambulatory during the past six months and usually afebrile, but had frequent recurring "colds" with exacerbation of symptoms.

On physical examination April 4, 1944, the patient was found to be a well-nourished, well-developed young woman of 22 years who seemed to be suffering from chronic malaise but was not acutely ill. A constant harassing, productive cough was the predominant symptom. There was moderate clubbing of the fingers and toes and a healed scar in the right axilla. With these exceptions, all of the positive physical findings were limited to her chest. Dullness, increased tactile fremitus and whispered voice, and prolonged expiration were present over the region of the right upper lobe. Râles were present over the lower half of this area. Roentgenograms of the chest showed the right leaf of the diaphragm elevated and the presence of a dense zone of fibrosis extending from the right hilum to the chest wall, presumably in the lower part of the right upper lobe (Fig. 5).

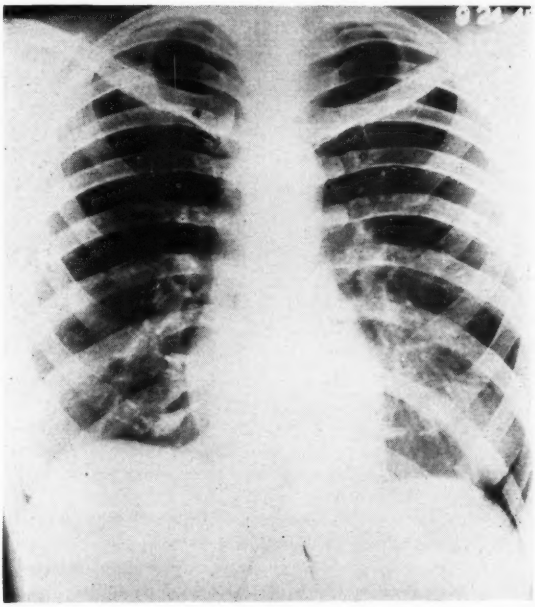

Fig. 3.—This film shows the same patient three months later. There has been a complete disappearance of the shadows from the right upper lobe, and the patient is entirely well.

Laboratory examination showed the Kahn, Kline, and Mazzini tests negative. The urine was normal. Her hemoglobin was 13.5 Gm. or 87 per cent with a white blood count of 8,500 and a differential count of segmented polymorphonuclears 65 per cent, eosinophiles 0, basophiles 0, monocytes 1 per cent, large lymphocytes 2 per cent, and small lymphocytes 32 per cent. The sputum was purulent, greenish in color, and foul in odor. It was negative

for acid-fast organisms but contained numerous gram-positive and gram-negative cocci and bacilli, numerous vibrios and fusiform bacilli, and moderate numbers of spirochetes of the *T. macrodentium* and *T. microdentium* types.

*Diagnosis.*—The diagnosis of chronic pulmonary abscess of the fusospirochetal variety was made and lobectomy was advised. The patient emphatically refused to consider an operation and requested medical treatment although she was told that improvement with medical treatment was very unlikely and a cure practically impossible.

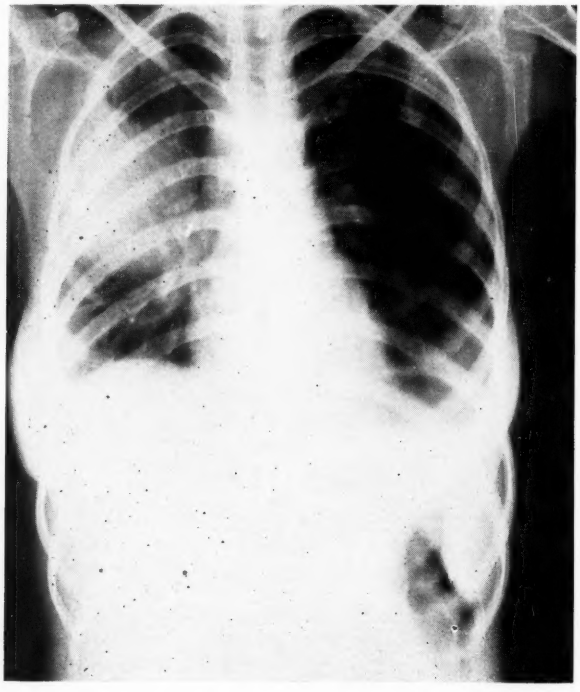

Fig. 4.—Case 1. The x-ray film shows a dense pneumonic process in the central portion of the right lung field. This infection failed to respond to sulfonamides and progressed to definite cavity formation which necessitated open operation and drainage.

I wish to thank Dr. R. B. Davis, of Greensboro, N. C., for permission to use this film.

*Treatment.*—The treatment in this case of chronic fusospirochetal pulmonary abscess was long and complicated and was characterized by the application of a number of well-known medical procedures in a definite sequence. In previous cases, none of these procedures either alone or in haphazard combination gave more than partial or temporary improvement. The patient remained ambulatory, returning to the hospital at frequent intervals for examination and treatment for the first six weeks and then at biweekly, monthly, and finally three-month intervals for the remainder of the period of treatment. Postural drainage, which had been employed for eighteen months, was continued and vitamins and iron were added to the diet. No restrictions were made to her previous routine of living.

An autogenous vaccine was prepared from a mixture of the anaerobic organisms grown from her sputum. Intradermal skin tests revealed that she was definitely sensitive to this mixture. Desensitization by subcutaneous injection with a dose which gave neither local nor constitutional reaction was begun. The dose was increased by 0.1 c.c. three times each week and continued for six weeks.

Sulfadiazine in doses of 1 Gm. every four hours except during the period of sleep at night was started and continued for thirty days.

Neoarsphenamine in 0.6 Gm. doses was administered intravenously each week for six weeks.

After four weeks of desensitization with the vaccine and thirty days of sulfadiazine, potassium iodide therapy was started. A saturated solution of potassium iodide was employed and the initial dose was 1 drop three times a day in one ounce of water. The potassium iodide was increased by one drop each day, *not one drop each dose*. The patient was told that the iodide was being given to accelerate the absorption of the granulomatous tissue in the diseased area and that hemoptysis might occur as the dose was increased. She was instructed to discontinue the potassium iodide if blood were seen in the sputum, remain in bed for forty-eight hours after the sputum was free of blood, and then begin the potassium iodide again with the initial dose of 1 drop three times a day. Hemoptysis did occur on four different occasions during the next four months at a dose level of 6 to 10 drops of potassium iodide three times daily. Possibly because of the previous explanation and warning, the patient was not at all alarmed by the hemoptyses.

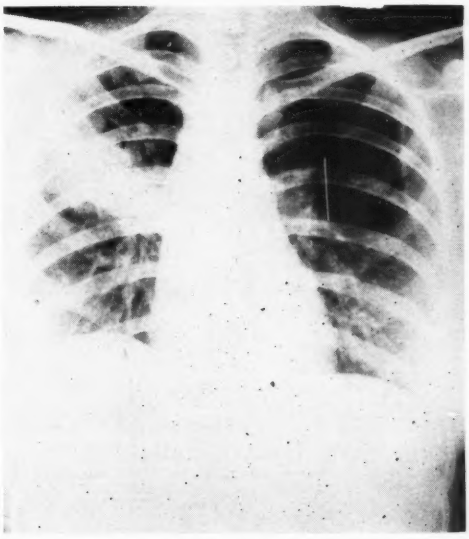

Fig. 5.—Case 1. This film shows a dense process in the lower part of the right upper lobe which is the residue of infection after twenty months of treatment, including open operation and drainage.

By May 18, 1944, six weeks after treatment began, the patient was feeling somewhat better. The sputum was reduced by 10 per cent and had lost the foul odor, but there were no changes in the physical findings or in the film of the chest.

After another month of treatment, on June 17, 1944, the patient reported that she felt much better. The sputum was reduced by 25 per cent and now had a yellowish tinge instead of the original greenish color. There were fewer râles in the right upper lobe, but the film of the chest remained unchanged.

By July 17, 1944, the patient seemed much stronger. The sputum was reduced by another 25 per cent and was produced almost exclusively by postural drainage. Fewer râles were heard in the right upper lobe, and films of the chest showed a 25 per cent reduction in the size of the lesion. Since the patient was no longer having hemoptyses, the dose of iodides reached the maximum of 20 drops three times a day; then it was reduced to 3 drops three

times a day and again carried up to the maximum of 20 drops three times daily. This procedure of increasing and decreasing the dose was continued throughout the period of treatment.

After another three months, on Nov. 1, 1944, the patient looked fine and the sputum was reduced to 8 c.c. daily. There was a striking reduction in dullness noted in the right upper lobe, and only an occasional râle could be elicited by an expiratory cough. There was an additional 10 per cent reduction in the size of the lesion by x-ray.

Films of the chest made Jan. 10, 1945, showed increasing fibrotic changes in the lesion with some slight reduction in the size of the diseased area.

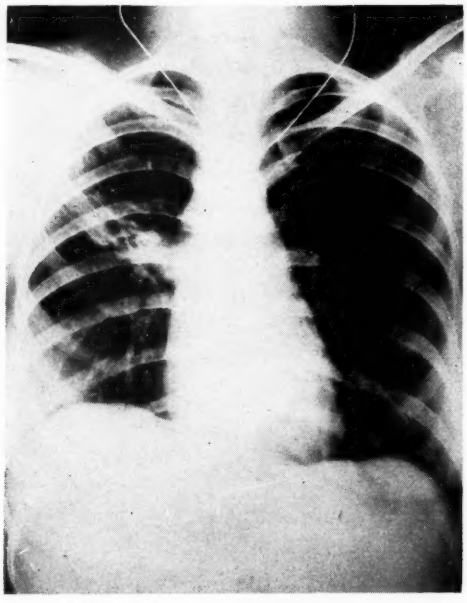

Fig. 6.—Case 1. This chest film was made fourteen months after medical treatment was started in this case. There is still some dense fibrous tissue present in the lower portion of the right upper lobe and some areas of decreased density which suggest multiple cavity formation although the patient has had no cough or sputum for many months. Another film made six months later showed the same findings.

After approximately one year of treatment the patient reported March 3, 1945, that she felt even better than she did before the original tonsillectomy. She had no cough, no sputum, and not even a cold during the past winter. The fibrous lesion in the lung was unchanged by x-ray (Fig. 6).

Potassium iodide therapy was discontinued June 30, 1945. The patient was in excellent condition and had no cough or sputum.

The patient was still well and free of all symptoms when examined Dec. 5, 1945, although the residual fibrous lesion in the lung persisted unchanged.

*Summary of Case.*—A young married woman of 20 years of age developed a pulmonary abscess after tonsillectomy. The infection was not controlled by sulfonamide therapy, and the abscess was drained through the chest wall fifteen weeks after the tonsillectomy; she was critically ill for six weeks and remained in the hospital for six months. At the time of discharge the operative wound was still draining and she was raising three ounces of purulent sputum daily. The sinus in the chest wall closed four months later, but she remained chronically ill with purulent sputum and occasional hemoptyses for the next eight months.

She was examined at Duke Hospital twenty months after the original tonsillectomy, where a lobectomy was advised but refused by the patient.

The medical treatment given this case of chronic pulmonary abscess consisted of: (1) desensitization over a 45-day period with a vaccine prepared from anaerobic organisms grown from her sputum; (2) sulfadiazine for thirty days; (3) neoarsphenamine in 0.6 Gm. doses each week for six weeks, followed by (4) potassium iodide therapy for fourteen months. Hemoptysis occurred four times during the first four months of the iodide therapy at a dose level of 6 to 8 drops three times a day, but did not recur with 20 drops three times a day taken in the course of the treatment when the sputum was scant in amount and the pulmonary lesion was fibrotic.

The patient has been in excellent condition for eight months, free of cough and sputum, but still has a fibrous scar in the lung.

## DISCUSSION

The prognosis in pulmonary abscess depends upon a number of factors, such as the type of abscess, whether single and peripheral or multiple and complicated by bronchiectasis; whether the infection is a primary aspiration or secondary to chemical irritation from a peanut or gastric secretions, or mechanical from pulmonary thrombosis and infarction or aspiration of a solid foreign body. The type of bacterial infection alters the prognosis and necessitates certain modifications in treatment. Our experience coincides with that of Touroff and Neuhof[51] who state that nonputrid pyogenic abscesses respond poorly to open drainage. In this group belongs the type of case which Neuhof and Thomas[31] call "suppurative bronchopneumonia." These patients should be treated with sulfonamides and penicillin and lobectomies or pneumonectomies performed if satisfactory improvement does not result. Most of our cases following aspiration of peanuts have required lobectomies.

Abscesses of the fusospirochetal type should be diagnosed in the first week or ten days of the disease, dating the onset from the first febrile rise, and treated intensively with penicillin with or without supplementary arsenicals, sulfonamides, or streptomycin. If the patients do not make dramatic improvement, they should be operated on before the end of the sixth week. Clinical improvement alone should not be accepted as a satisfactory criterion. There should be a progressive clearing of the pulmonary shadows and the patient should be followed until the lungs are clear by chest roentgenogram.

In general, the medical treatment of acute pulmonary abscesses has been distressingly bad during the past ten years. The errors have been primarily those of the internist rather than the thoracic surgeon. The internist too frequently has failed to determine the etiologic agent responsible for the pulmonary abscess; has often given inadequate treatment; and when the patient has made a partial recovery, has prolonged the medical treatment to a point where the patient becomes a poor surgical risk.

In Table II is presented the results of surgical treatment and in Table III the results of medical treatment. The mortality of 32.7 per cent for the patients treated surgically is not much better than the medical mortality of 34.7 per cent. Certainly a considerable part of this relatively high surgical mortality has resulted from the poor medical treatment given prior to operation.

A better idea of the results of medical treatment can be obtained by considering all patients in Tables II and III as being medical patients before they underwent operation. In Table XI we have added the patients who received surgical treatment to those who received nothing but medical treatment and recalculated the results. For example, Allen and Blackman report fifty-five patients as receiving medical treatment alone and thirty-eight as receiving surgical treatment, or a total of ninety-three; but certainly the thirty-eight received—or failed to receive—some kind of medical therapy prior to operation. In this group of 1,498 patients listed in Table XI, the mortality from medical treatment is 21 per cent in contrast to a mortality of 34.7 per cent as shown in Table III. The recoveries, on the other hand, are only 19 per cent in contrast to 31.3 per cent as recorded in Table III. The most significant finding is the 60 per cent of this series of 1,498 patients who were still chronically ill after medical treatment. Seven hundred and forty-four of these were then transferred to the surgical departments for operation with the results recorded in Table II. Not only is the percentage of failures greater with medical treatment, but the patients are generally in much poorer condition and usually are not able to work, while many of the patients listed as chronic after surgery have only minor disability and are able to earn their living.

TABLE XI. PULMONARY ABSCESS MORTALITY; MEDICAL TREATMENT

| AUTHOR | LOCATION | NUMBER | DIED | | WELL | | CHRONIC | |
|---|---|---|---|---|---|---|---|---|
| | | | NO. | % | NO. | % | NO. | % |
| Allen and Blackman*[2] | Detroit | 93 | 14 | 15.0 | 30 | 32.3 | 49 | 52.7 |
| Cutler and Gross[8] | Boston | 83 | 8 | 9.6 | 20 | 24.1 | 55 | 66.3 |
| Shaw and Blackman[41] | Ann Arbor | 227 | 27 | 11.9 | 49 | 21.6 | 151 | 66.5 |
| Shaw[41] | Dallas | 49 | 2 | 4.1 | 11 | 22.4 | 36 | 73.5 |
| Lueth*[28] | Chicago | 96 | 18 | 18.7 | 45 | 46.9 | 33 | 34.4 |
| Rosenblatt[39] | New York | 93 | 34 | 36.6 | 4 | 4.3 | 55 | 59.1 |
| Jackson and Judd[18] | Philadelphia | 124 | 23 | 18.6 | 33 | 26.6 | 68 | 54.8 |
| Kline and Berger[21] | Cleveland | 57 | 26 | 45.6 | 31 | 54.4 | 0 | 0 |
| D'Ingianni[9] | New Orleans | 417 | 141 | 33.8 | 8 | 1.9 | 268 | 64.3 |
| Overholt and Rumel[34] | Boston | 81 | 10 | 12.3 | 5 | 6.2 | 66 | 81.5 |
| Arbuckle[3] | St. Louis | 43 | 0 | 0 | 19 | 44.2 | 24 | 55.8 |
| Smith | Durham | 135 | 11 | 8.1 | 29 | 21.5 | 95 | 70.4 |
| Total | | 1498 | 314 | 21.0 | 284 | 19.0 | 900 | 60.0 |

*Calculated from data given by the author.

One case of chronic pulmonary abscess of the fusospirochetal type is reported where the treatment consisted of sulfonamide therapy, neoarsphenamine injections, desensitization with an autogenous vaccine, followed by the administration of potassium iodide. Since occasionally patients with chronic abscesses make a complete recovery, no conclusions can be drawn from this isolated case.

## CONCLUSIONS

1. The mortality in a series of 2,166 cases of pulmonary abscess collected from representative clinics from 1936 through 1944 was 32.7 per cent.

2. Early medical diagnosis of the pneumonic infiltration which precedes the abscess is essential for successful treatment with penicillin, arsenicals, or streptomycin.

3. Sulfonamide therapy definitely is helpful in pulmonary abscesses caused by gram-positive cocci.

4. Sulfonamide therapy in the fusospirochetal types of infection gives temporary improvement but fails to cure, and the patient's progress to chronic abscesses which will not respond to penicillin or arsenicals.

5. If the patient is not improving clinically and clearing steadily, as shown in serial x-ray films, by the end of the fourth to sixth week of the disease, he should be referred to the thoracic surgeon for operation.

6. Inadequate early treatment and prolongation of medical treatment past the optimal time for operation are the chief causes for the high mortality from pulmonary abscess.

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# THORACIC CASUALTIES FROM AN ISLAND CAMPAIGN IN THE PACIFIC

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THIS study concerns 172 battle casualties receiving thoracic wounds in the final campaign in the Pacific. Only patients with wounds penetrating the pleura are included. They represent all the thoracic wounded passing through the central Pacific from this campaign receiving wounds penetrating the pleura.

The number of men with thoracic wounds dying in division or field hospitals is not known.

No evacuation hospitals were in the chain of evacuation. Early definitive treatment was carried out in the field hospitals and on board hospital ships. Evacuation was by ship and plane 1,600 miles to forward general hospitals, Army Station hospitals and Navy Base hospitals, thence by air or ship to the thoracic center in the central Pacific, a distance of 4,000 miles.

This record of the treatment and evacuation of thoracic casualties is not offered as an ideal system. It simply illustrates the tremendous problems which arose in the Pacific due to the great distances to be covered. No trained thoracic surgical teams were available for early definitive treatment. In the four general and base hospitals supplying the middle link in the chain of evacuation, there were only two surgeons with appreciable training in thoracic surgery.

It will be noted in Table I, that the number of wounds from high explosives and from bullets in this campaign differs from that in other theaters.[1]

To use the classification of Welch and Tuhy[2] there were twelve thoracoabdominal wounds, five thoracoretroperitoneal wounds (two of which are uncertain) and no abdominothoracic wounds, making a total of seventeen (9.9 per cent) wounds that penetrated the diaphragm.

A history of hemoptysis was obtained in 129 (75 per cent of the patients which lasted on the average of 4.6 days per patient. All but two cases had a history of dyspnea varying from one to fifty days; the average being 12.7 days. X-ray evidence of pneumothorax was present in forty-two (24.4 per cent) casualties. There were two (1.2 per cent) casualties with tension pneumothorax. One was treated with a flutter valve and the other by repeated aspiration. Hemothorax was present in 166 casualties. In seventy-five (43.6 per cent) it was less than one-third and in ninety-one (53.9 per cent) it was over one-third.

## TREATMENT IN DIVISION

The Division Medical Services gave 41 units of whole blood to twenty-six (15.0 per cent) casualties, an average of 1.6 units of blood per patient. They gave 141 units of plasma to eighty (46.5 per cent) casualties, an average of

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TABLE I. TYPE OF WOUNDS

| WOUND | | | SUCKING | | RIB FRACTURE | | |
|---|---|---|---|---|---|---|---|
| TYPE | NO. | % | NO. | % | NO. | % | NO. RIBS |
| High Explosive | 96 | 55.8 | 62 | 64.6 | 28 | 29.1 | 38 |
| Perforating | 3 | | | | | | (1.3 Ave.) |
| Penetrating | 93 | | 50 | 66.6 | 40 | 53.3 | |
| Bullet | 75 | 43.6 | | | | | |
| Perforating | 65 | | | | | | 73 |
| Penetrating | 10 | | | | | | (1.8 Ave.) |
| Bayonet | 1 | 0.1 | 1 | 0.1 | 0 | | |

1.8 units of plasma per patient. Five thoracenteses were done in the clearing stations on four (2.3 per cent) casualties with an average of 500 c.c. of blood being withdrawn per aspiration. In one patient an air flutter valve was inserted to relieve tension pneumothorax. There were seventy-nine casualties with sucking wounds that had pressure dressings applied.

The average elapsed time between the hour of wounding and arrival at a field hospital was 6.8 hours. If ten casualties were to be admitted that were delayed for long periods of time due to the intensity of the battle or because they were wounded in remote areas, then the average evacuation time for those remaining would be 5.4 hours. It is interesting to note that in addition to the traditional litter-ambulance method of evacuation, two casualties were evacuated on LSTs and three were evacuated by liaison planes.

### TREATMENT AT FIELD HOSPITALS

Under this heading will also be included all treatment given by hospital ships which early in the campaign took casualties directly from the Division Medical Service or soon after their admission to the field hospitals because of the congestion that existed there.

Ninety-four (54.6 per cent) casualties received a total of 226 thoracenteses an average of 2.4 aspirations per patient with an average amount of 367.4 c.c. being withdrawn per aspiration. (Note in twenty-three instances the amount withdrawn was not recorded). All but twenty-four (13.9 per cent) of the wounds were debrided, of which nineteen were due to high explosive fragments and nine were due to bullets. Of the 144 wounds that were debrided, ninety-nine (57.6 per cent) were primarily sutured. The remainder had petrolatum gauze packs or dressings applied. Of the ninety-nine patients receiving primary suture, the defect was so large in thirteen patients that a muscle flap was used to close the defect. In this group of thirteen patients, four subsequently developed empyema, which in two of the cases apparently was due to an infection and breakdown of the closure with the formation of a pleurocutaneous sinus. Also in this group of thirteen muscle flap closures two patients developed an atalectasis and another clotted hemothorax.

The records were not sufficiently detailed to permit an analysis of the thoracotomies done at the field hospitals. There were seven recorded. One was for the removal of a metallic foreign body. The other six consisted of an enlargement of the wound for the removal of shattered rib fragments. It is be-

lieved that there were more, for several of the healed scars suggested that a limited thoracotomy had been done.

Laparotomies were done on nine (5.2 per cent) patients because associated intraabdominal wounds were suspected. Of these nine laparotomies, four patients had wounds of the liver that were repaired, two had high explosive fragments removed from the abdominal cavity (location not given) and in three no details of the laparotomy accompanied the patient. In four cases lacerations of the diaphragm were sutured. There were eight other patients with thoracoabdominal wounds who did not receive laparotomies. These x-ray plates showed that six had small high explosive fragments in the liver. In one the fragment was in the body of a lumbar vertebra and in another a bullet was adjacent to the body of a lumbar vertebra.

There were eight metallic foreign bodies removed. Three of these were removed from the abdomen at the time of laparotomy. Four others were removed from the chest wall (each of these had previously traversed the thoracic cavity). One thoracotomy was done for the removal of a metallic foreign body.

The value of intercostal nerve blocks to control pain has been mentioned by Blades,[3] Snyder,[4] and others. In this group of cases it was done only once at one of the field hospitals.

There were 111 (64.5 per cent) cases that received 356 units of blood an average of 3.2 units per case and sixty (34.9 per cent) cases that received 99 units of plasma, an average of 1.6 units per case. There is no mention made in the records that any of the blood aspirated from the hemothoraces was used for autotransfusion. There were eight (4.7 per cent) casualties whose only treatment was a dressing before they were evacuated.

During the earlier phases of the campaign, patients were evacuated chiefly by hospital ship, but as the air transport service became better organized during the campaign, the majority were evacuated by air to forward bases on islands 1,600 miles away. The usual flight was between 8,000 and 11,000 feet. There were 104 patients evacuated by ship and sixty-eight by air transport. Of those sixty-eight going by air, nineteen complained of slight dyspnea at some time during the trip, eighteen noted moderate dyspnea, and in five patients the dyspnea was severe, requiring oxygen for relief. These casualties reached the forward bases on an average of 9.1 days following their injury.

### TREATMENT AT GENERAL HOSPITALS ON FORWARD BASES

In sixty (34.9 per cent) patients it was found that treatment in the forward areas had been adequate so that only convalescent care was needed at these general hospitals. Fifty (29.1 per cent) patients were given 139 units of blood, an average of 2.8 units per case. There were 239 thoracenteses done on ninety casualties, making an average of 2.7 aspirations per patient. An average amount of 404.8 c.c. was withdrawn per aspiration.

Five patients with empyema had a rib resected to establish open drainage. Four of these were eventually evacuated to the mainland for further treatment. The lung of the fifth patient completely re-expanded and he was discharged

to duty. Six casualties had foreign bodies removed. Three were removed by elective thoracotomy, one from the chest wall, one at the time of a decortication, and one through an esophagoscope. All were sent to duty without complications except one who developed a postoperative collapse of the entire left lung. Re-expansion was obtained only after a decortication was done at this thoracic center.

Decortications were done on four casualties. In three a good result was obtained and they were returned to duty. The fourth arrived at the thoracic center with an infected sinus in his chest wall due to the presence of a neglected drainage catheter. The lung completely expanded, the infection subsided, and the sinus closed while the patient was in this hospital.

Evacuation to the central pacific thoracic center, 4,000 miles, was usually by air, either continuoss, stopping only for gas twice, or with one stop of a few hours at about the middle of the trip. The usual flight was between 8,000 and 11,000 feet. There were 149 casualties evacuated by air and twenty-three by ship. Of those evacuated by air, thirty-four complained of slight dyspnea at some time during the trip, eleven noted moderate dyspnea, and six were severely dyspneic, requiring oxygen for relief. Casualties arrived at the thoracic center on an average of 39.7 days following their injury.

### TREATMENT AT THORACIC CENTER OVERSEAS

Convalescent care only was necessary for 112 (65.1 per cent) of the patients. There were thirty-four patients in this group who had a residual hemothorax which required an average period of 24.8 days to complete its absorption before the patient could be returned to duty. Thirty-eight (22.1 per cent) casualties required an average of 3.1 thoracenteses. Transfusions of whole blood were given to sixteen (9.3 per cent) cases, an average of 3.2 units being given per patient. Delayed wound closures were done on sixteen (9.3 per cent) patients.

There were twenty-seven foreign bodies removed; thirteen by elective thoracotomy, eight at the time of decortication, and six were removed from the chest wall. Fourteen patients required a decortication; ten for clotted hemothorax, and four for empyema. Two cases had an open drainage for massive empyemas.

### FOREIGN BODIES

A summary of the treatment of foreign bodies in this series indicates that a total of forty-one foreign bodies were removed from the following locations; lung fifteen, chest wall eleven, mediastinum two, heart wall one, lung or pleural cavity during decortication nine, and abdomen at the time of laparotomy three. One or more of the following indications for removal existed; large size (over 1.5 cm. in diameter) twenty-three proximity to vital structures four, sharp, irregular edges four, small abscess, about the foreign body three, hemoptysis two, foreign body in an empyema cavity two, and pain and cough one.

Twenty-two of these patients had good results and were returned to duty. The remaining nineteen were evacuated to the mainland; eleven for other dis-

ability not connected with the chest wound, seven for convalescence following a decortication and one because of dyspnea and easy fatigability. One developed a bronchopleural fistula and on admission to the thoracic center he had a total collapse of his left lung. This responded well to decortication.

Thirty-two casualties were discharged to duty with small retained metallic foreign bodies. There were seventeen more with retained metallic foreign bodies that were evacuated to the mainland; seven for further observation and ten for reasons not related to the retained foreign body.

### HEMOTHORAX

In this series of cases it is noted that fifty-two casualties received thoracenteses on the first day of their injury, fourteen on the second day, seven on the third day, eleven on the fourth day, five on the fifth day, four on the sixth day, twenty-five on the seventh to fourteenth days, thirteen on the fourteenth to twenty-first days, and six on the twenty-first to fifty-sixth days. There were thirty-five casualties that had no thoracenteses. There is nothing to indicate that bleeding was reactivated because of early thoracenteses in any of these patients. There was no intentional air replacement of the aspirated blood at the time of thoracenteses, which is in accord with the current feeling.[1, 5, 6] By the time that these casualties reached the thoracic center, the hemothorax in most cases was stabilized and undergoing absorption. There were thirty-four patients with small hemothoraces who required an average of 24.8 days to absorb the remainder of their fluid. In twenty-five more hemothoraces the fluid cleared with a combination of aspiration and absorption.

There were eighteen patients who received decortications. A brief summary of these cases appears in Table II.

The decortications were done on the average of 5.5 weeks after injury. The shortest interval was two weeks and the longest was eleven weeks following injury. No particular technical difficulties were experienced in doing the decortications which is in agreement with the experience of Churchill,[5] Tuttle and associates,[7] Lush and associates,[9] Samson and associates[12] and others. Good results were obtained in fourteen cases. Two patients had good re-expansion of their lung but their convalescence was prolonged and at the time of evacuation they continued to have a decreased expansion of the chest on the injured side. Two poor results were obtained; one patient had a considerable amount of deformity of the chest wall with a markedly thickened pleura and the other had a persisting bronchopleural fistula with partial collapse of the injured lung. Seven of these patients were discharged to duty, nine were transferred to the mainland for convalescent care only, and two were evacuated for further treatment.

### EMPYEMA

In this series thirteen patients had frank infection of their hemothoraces. This is an incidence of 7.6 per cent which compares very favorably with the reports of Tuttle and associates, (16.8 per cent),[7] Nicholson and Scadding (33 per cent),[8] Burford (11.2 per cent), [10] and Pain and Plankers (11.0 per cent).[11] A summary of these thirteen empyemas is presented in Table III.

TABLE II. SUMMARY OF CASES TREATED BY DECORTICATION

| | CASE | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wound | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | TOTAL | % |
| Penetrating | B | – | H | – | H | H | H | H | – | H | H | H | B | H | H | H | H | H | 15 | 83.3 |
| Perforating | – | B | – | B | – | – | – | – | B | – | – | – | – | – | – | – | – | – | 3 | 16.7 |
| Sucking | 1 | 1 | 1 | – | 1 | – | 1 | 1 | – | 1 | 1 | 1 | 1 | 1 | – | 1 | 1 | 1 | 14 | 77.7 |
| Pneumothorax | 1 | ? | – | – | 1 | – | 1 | ? | – | 1 | – | 1 | 1 | ? | 1 | ? | 1 | 1 | 9 | 50.0 |
| No. fractured ribs | 2 | – | – | 2 | – | – | – | 1 | 5 | – | – | 1 | 1 | – | – | – | 1 | – | 7 | 38.9 |
| Days of hemoptysis | 2 | 1 | 4 | 7 | 1 | 4 | 6 | – | 1 | – | 4 | 7 | 10 | 1 | – | 4 | 45 | – | 14 | 77.7 |
| No. thoracenteces | 3 | 4 | 2 | 12 | 8 | 5 | 20 | 4 | 27 | 5 | 7 | 10 | 6 | 3 | 7 | 2 | 6 | 12 | 143 | 7.9 |
| Days until first tap | 5 | 4 | 13 | 2 | 1 | 14 | 4 | 26 | 1 | 1 | 1 | 1 | 10 | 16 | 2 | 11 | 1 | 2 | 108 | 6.0 |
| F. B. present at time of clot | 1 | – | 1 | – | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | – | 1 | 15 | 83.3 |
| Week of decortication | 10 | 3 | 7 | 4 | 5 | 5 | 5 | 9 | 7 | 5 | 2 | 8 | 2 | 4 | 2 | 7 | 11 | 4 | 100 | 5.5 |

B = Bullet wound; H = High explosive.

TABLE III. SUMMARY OF 13 CASUALTIES WITH EMPYEMA

| | CASE | | | | | | | | | | | | | TOTAL | AVERAGE (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | | |
| Penetrating | H | H | H | – | H | B | H | H | H | – | – | H | H | 10 | 76.9 |
| Perforating | – | – | – | B | – | – | – | – | – | B | B | – | – | 3 | 23.1 |
| No. fractured ribs | – | 1 | 1 | 5 | 2 | – | 1 | – | – | 4 | 3 | 1 | – | 8 | 61.5 |
| F. B. present at onset of the empyema | 1 | 1 | 1 | 1 | 1 | – | 1 | ? | 1 | – | – | – | – | 7 | 53.8 |
| Wound infected with draining sinus | – | 1 | 1 | – | 1 | – | 1 | – | – | – | – | – | – | 4 | 30.8 |
| Weeks following wound | 4 | 3 | 6 | 6 | 7 | 3 | 8 | 3 | 6 | 4 | 8 | – | – | – | 5.2 |
| Prevailing organism | ? | Sa | Sa | Bp | ? | ? | Sa | ? | Sa | ? | ? | Sa | Sa | – | – |
| Treatment | O | O | D | D | O | O | D | O | D | O | O | C | C | – | – |
| Evac. for convalescence | – | – | 1 | 1 | d | – | 1 | – | 1 | – | 1 | 1 | 1 | 7 | 53.8 |
| surgery | 1 | 1 | – | – | d | 1 | – | 1 | – | 1 | – | – | – | 5 | 38.2 |

Sa = *Staphylococcus aureus;* Bp = *B. proteus;* ? = not recorded; D = decortication; O = open drainage; C = closed drainage; H = high explosive; B = bullet.

TABLE IV. SUMMARY OF THE 66 PATIENTS EVACUATED TO THE MAINLAND

| | | |
|---|---|---|
| Evacuated for cause not related to the chest wound | | 34 |
| Evacuated because of the chest wound and its complications | | 32 |
| For convalescence only (would be able to do duty within a few weeks) | 18 | |
| Observation for retainded metallic foreign bodies | 7 | |
| Chronic empyema | 5 | |
| Pulmonary tuberculosis | 1 | |
| Traumatic cyst of the lung | 1 | |
| | 32 | |

TABLE V. SUMMARY OF THE COMPLICATIONS

| COMPLICATIONS AND AREAS AFFECTED | NO. | % |
|---|---|---|
| Lungs and pleura | | |
| Clotted hemothorax (large) | 16 | 9.3 |
| Empyema | 13 | 7.6 |
| Bronchopleural fistula | | |
| Following decortications | 7 | 4.1 |
| Following removal of MFB | 3 | 1.8 |
| Atalactasis | 2 | 1.2 |
| Tuberculosis | 1 | 0.6 |
| Traumatic cyst of the lung | 1 | 0.6 |
| Persistent pleuritic friction rub | 1 | 0.6 |
| Heart and great vessels | | |
| Tachycardia | 3 | 1.8 |
| Traumatic myocarditis | 1 | 0.6 |
| Aortic diastolic murmur | 1 | 0.6 |
| A-V aneurysm (rt. subclavian art.) | 1 | 0.6 |
| Liver | | |
| Acute hepatitis | 2 | 1.2 |
| Multiple abscesses | 1 | 0.6 |
| Kidney | | |
| Sulfadiazine crystal colic | 1 | 0.6 |
| Spinal cord | | |
| Transection (partial) | 1 | 0.6 |
| Concussion | 1 | 0.6 |
| Thrombophlebits | 3 | 1.8 |
| Decubitus ulcer | 1 | 0.6 |

The two patients treated by closed drainage had small empyema pockets that formed after decortication; one the result of a bronchopleural fistula and the other in the sinus left by the drainage catheter. Both cleared promptly and completely on drainage. The four patients with empyemas that were decorticated all healed well with complete re-expansion of their lungs. All but one of the empyemas treated by open drainage were evacuated to the mainland for further surgery. This one had a massive bile empyema and multiple liver abscesses and is the only patient in this series that died.

## RESULTS

A summary of the disposition of the 172 patients in this series indicates that 105 (61 per cent) were returned to duty and sixty-six (39 per cent) were evacuated to the mainland. (See Table IV). All complications are summarized in Table V.

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# TRAUMATIC DIAPHRAGMATIC HERNIA

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DIAPHRAGMATIC hernias of traumatic origin have been seen with increasing frequency during the period of the war. Many of these have resulted from penetrating wounds and injuries; others have been caused by crushing injuries and automobile accidents, and a few have resulted from incidents causing a sudden increase in the intra-abdominal pressure. The purpose of this paper is the presentation of twenty-eight traumatic diaphragmatic hernias operated upon at Kennedy General Hospital during the past three years. Injuries of the diaphragm were associated with other injuries, and with few exceptions these injuries were repaired when the original operation was performed. Of the approximately 2,000 patients with chest wounds who were admitted to Kennedy General Hospital from January, 1944, to April, 1946, only sixteen had diaphragmatic hernias. The twelve others had diaphragmatic hernias resulting from injuries unrelated to a battle.

## ETIOLOGIC FACTORS

Penetrating wounds due to machine gun, rifle, or pistol bullets caused twelve hernias. Shell fragments caused the defect in four, and in one patient the injury was the result of a stab wound. Automobile, truck, or jeep accidents caused the diaphragmatic injury in nine patients; one injury was the result of a fall, and another the result of jumping from a truck.

The diaphragmatic wounds were the result of either a penetration (seventeen) or rupture (eleven) of the structure. Much has been written about the contusion type of injury commonly seen in civilian practice and most often due to automobile accidents.

The embryology, development, anatomy, and location of anatomic diaphragmatic defects where hernias are prone to occur are described in the literature. We are unable to correlate anatomic weakness with the size and location of these hernias. (Diagram 1.) A small defect 1.5 cm. was found due to an automobile accident in one patient, while a 15 cm. defect was found in another patient who had fallen a short distance. Several small defects were the result of bullet wounds, but a very extensive diaphragmatic defect was the result of being subjected to machine-gun fire.

The diaphragmatic hernia occurred immediately in thirteen of the seventeen patients with penetrating injuries and in ten of the eleven contusion injuries. The absence of herniation after injury is shown in Figs. 3 and 5. A repair of the diaphragmatic injury was made at the original operation in six cases.

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Read at the Twenty-Sixth Annual Meeting of The American Association for Thoracic Surgery, Detroit, Mich., May 29, 30, and 31, 1946.

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It is obvious that increased abdominal pressure as a result of strain may be the immediate cause of the herniation through small defects in the diaphragm that are the result of previous injury. Occasionally, the original injury was

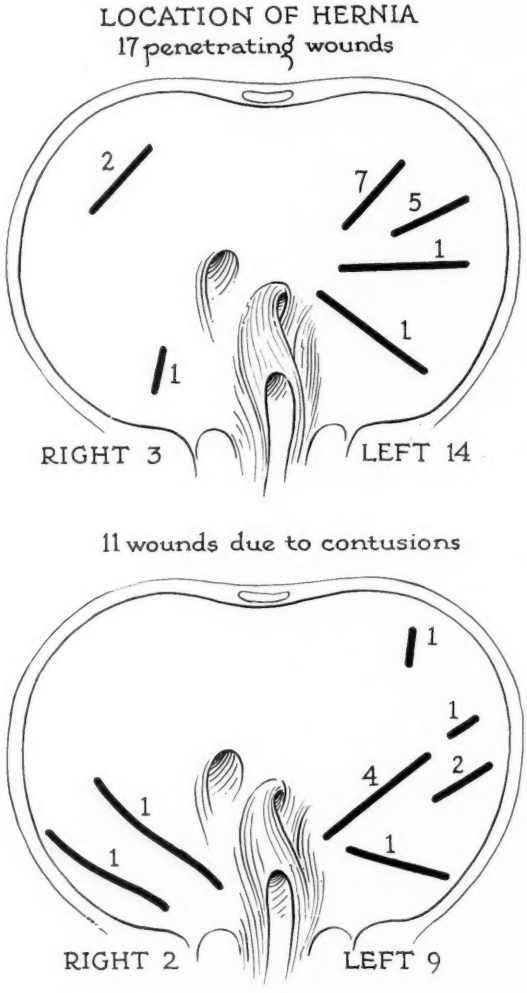



DIAGRAM 1.

insignificant and no thoracotomy was necessary. In only five of our cases was the injured diaphragm repaired at the front. The others had wounds produced by bullet or shell fragments which were so small that no herniation occurred until prolonged strain, or a sudden strain, caused enlargement of the defect. In one instance this was strikingly demonstrated when a soldier who had had a penetrating chest wound thirteen months previously suddenly developed acute

TABLE I. ETIOLOGIC FACTORS

| TYPE OF INJURY | NO. | TOTAL |
|---|---|---|
| Penetrating injuries | | 17 |
| Bullet wounds | 12 | |
| Shell fragment wounds | 4 | |
| Stab wounds | 1 | |
| Nonpenetrating injuries | | 11 |
| Automobile accidents | 9 | |
| Fall | 2 | |
| Total | | 28 |

TABLE II. HERNIATED ORGANS

| ORGAN AND SITE OF HERNIA | NO. | TOTAL |
|---|---|---|
| Through right diaphragm | | 5 |
| Liver | 4 | |
| Kidney | 1 | |
| Through left diaphragm | | 23 |
| Stomach | 2 | |
| Stomach and omentum | 2 | |
| Stomach and spleen | 1 | |
| Stomach and liver | 1 | |
| Omentum | 3 | |
| Colon and omentum | 4 | |
| Stomach and colon | 1 | |
| Stomach, colon, small intestines, and omentum | 3 | |
| Stomach, colon, small intestines, liver, and omentum | 2 | |
| Stomach, colon, small intestines, spleen, and omentum (One associated with a pericardial tear) | 2 | |
| Stomach, colon, small intestines, omentum, spleen and kidney | 1 | |
| Colon, small intestines, omentum, and spleen | 1 | |
| Total | | 28 |

TABLE III. SYMPTOMS OF LEFT DIAPHRAGMATIC HERNIA (23 CASES)

| TYPE OF HERNIATION | SYMPTOMS |
|---|---|
| Of sudden herniation of hollow viscus | Unconsciousness<br>Nausea and vomiting<br>Dyspnea<br>Epigastric pain |
| Of chronic herniation of hollow viscus | Epigastric pains, especially after meals or when recumbent<br>Indigestion<br>Flatulence<br>Dyspnea<br>Bubbling sounds in chest |
| Herniation of solid viscus | Pain in chest |

upper abdominal pain while carrying heavy sacks and was found to have almost complete herniation of his stomach into his chest (Fig. 7). Sudden acute symptoms were produced in another case by the soldier jumping from a truck. In this instance his colon herniated through a defect only 1½ cm. in diameter and by the time he was admitted to this hospital gangrene of the bowel had developed (Fig. 6). He made an uneventful recovery following resection of the colon and repair of the hernia. Three other patients who were known to have hernias of several months' duration developed acute obstruction while under observation here or at other hospitals. Emergency operation was successfully performed in each case.

Our first diaphragmatic hernia was in a man who had been shot through the right chest by a bullet in May, 1943. When seen in June he was found to be well and roentgenograms of the chest were not significantly abnormal, so that he was returned to limited duty. One year later he began having pains in his right lower chest and a rounded mass overlying the diaphragm was seen on the roentgenogram. Exploratory thoracotomy was performed and he was found to have a hernia of a portion of the right lobe of his liver through the diaphragm. X-rays of a similar case are shown in Fig. 3. These cases are cited because it is believed that many similar ones will arise during the course of the next few years.

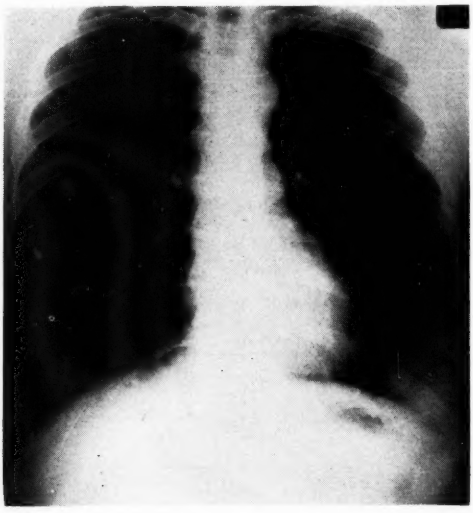


Fig. 14.—P. D. R. An asymptomatic lesion found on routine Army discharge film. The soldier was wounded at Pearl Harbor and had done duty for three years. The preoperative diagnosis was tumor or encapsulated hematoma.

## SYMPTOMATOLOGY

Herniation of solid viscera was associated with rather vague pain in the lower chest. When hollow viscera were herniated, symptoms of various types and severity developed. In eleven of these due to battle wounds associated with other injuries, the symptoms of the hernia were at first frequently masked. Later, epigastric pain, especially after meals and when the patient was recumbent, flatulence, indigestion, and dyspnea were noted. Several patients could hear and feel gurgling sounds in the chest.

In the instances of sudden herniation of a hollow viscus, the symptoms were more dramatic. In two instances unconsciousness occurred which could not be accounted for by the associated injuries. Dyspnea appeared in those cases in which the herniation caused considerable collapse of the lung. The other symptoms, pain, nausea, and vomiting, were dependent upon the extent of the herniation and the amount of obstruction produced.

Fig. 1*B*.—Photograph at operation showing the herniated omentum spread over chest wall.

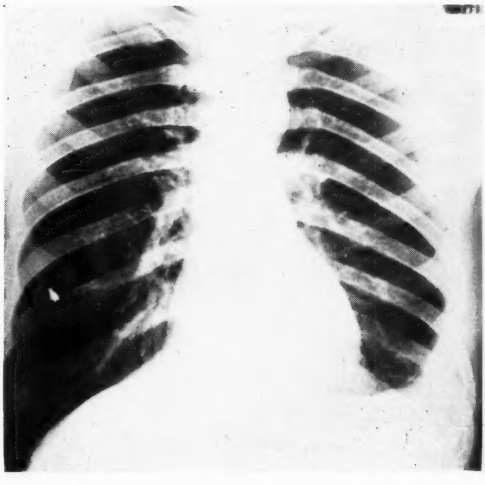


Fig. 1*C*.—Postoperative roentgenogram.

Exploration of a draining chest-wall sinus revealed an asymptomatic herniation of a portion of the omentum in two recurrences that followed repair of a diaphragmatic injury overseas.

### TREATMENT

Operative repair was successfully carried out in all cases. There was an immediate recurrence in one case which was promptly recognized and successfully repaired five months later. In all instances a transthoracic approach was used and, except in one case, was done under endotracheal anesthesia. The one exception was the case in which a preoperative diagnosis of encysted fluid was made and at operation a hernia of a portion of the right lobe of the liver was found.

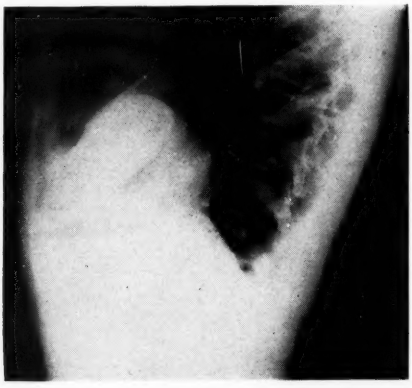


Fig. 2A.—C. J. F. Herniation of a cystic kidney following an automobile accident ten years previously.

The transthoracic approach was usually made through the bed of the eighth or ninth rib with the patient lying on his side. The excellent exposure so easily obtained by this route kept us from considering the abdominal approach. In a number of instances the herniated structures extended up to the dome of the thorax, and in such cases the adhesions present would have been handled only with the greatest of difficulty through an abdominal approach.

Occasionally, when the hernia was first exposed, it seemed that not enough of the diaphragm remained to allow adequate closure, but in every case after careful dissection, sufficient diaphragm was developed to permit satisfactory closure. In several instances it was necessary to dissect the extension of the diaphragm into the transversalis muscle to obtain closure without tension. Two rows of interrupted silk sutures were used, the second burying the first. When the diaphragm was detached from the chest wall, mattress sutures through the chest wall tied over tubes were employed to obtain a secure closure. This was followed by interrupted intrapleural sutures. In the first half of the series of cases the phrenic nerve was not always crushed unless the line of the defect was such that contraction of the diaphragmatic fibers caused a pull on the suture line. Following the immediate recurrence of one hernia after excessive

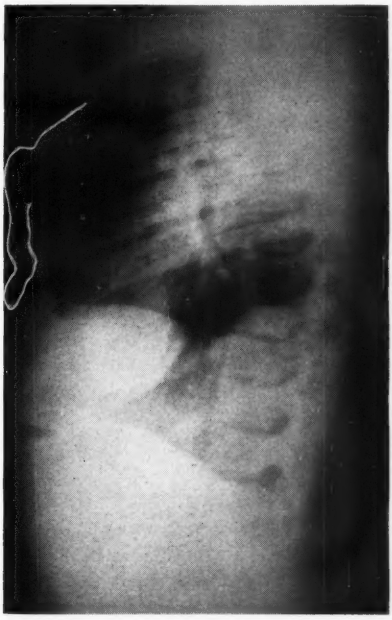
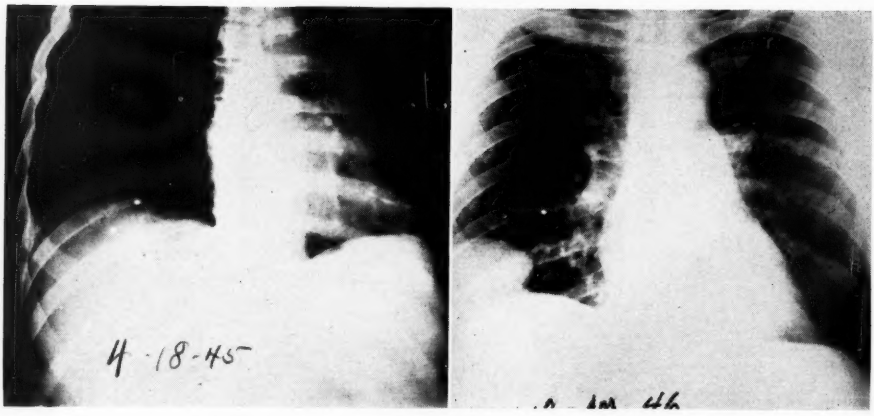


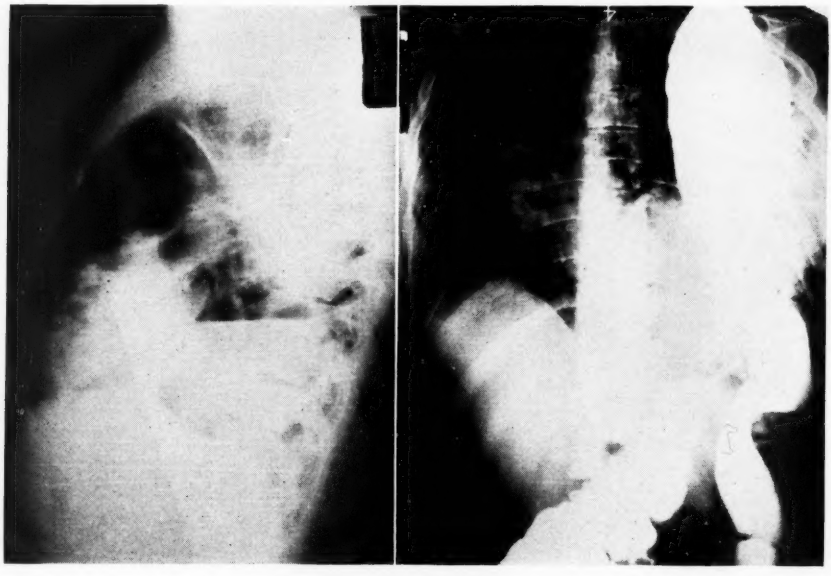
Fig. 2*B*.—One year after first repair elsewhere.

Fig. 2*C*.—Roentgenogram following nephrectomy and second repair of the hernia. Mattress sutures of tantalum wire were placed through the diaphragm and the chest wall and tied over rubber tubing because the diaphragm had been detached from the chest wall.




*A.* *B.*

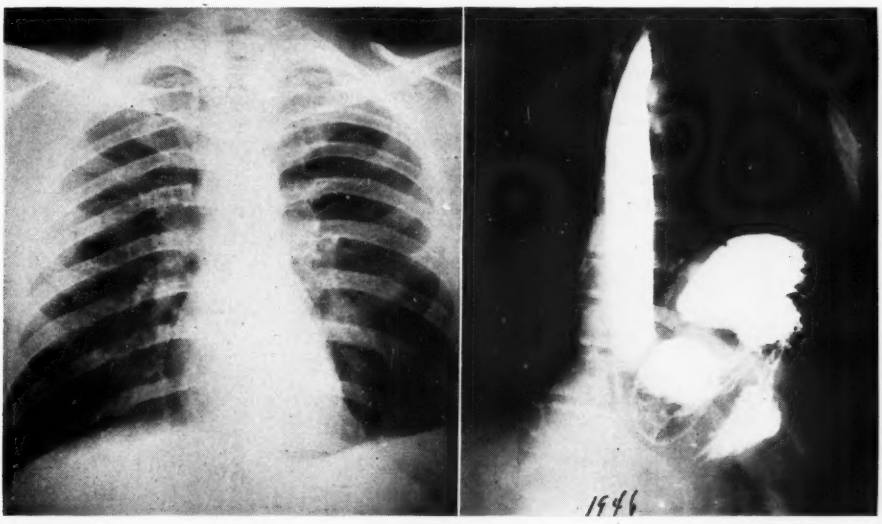
Fig. 3.—F. S. C. *A*, Film four months after a penetrating right chest wound showing the absence of herniation. *B*, film one year later showing herniation of the right lobe of the liver. Recovery from operation was uneventful.



*A.* *B.*

Fig. 4*A* and *B*.—L. M. L. Roentgenogram showing a large hernia found following a forced march with heavy field pack overseas. He was injured in an automobile accident several years previously.

diaphragmatic movements associated with tracheal aspiration, in which the diaphragm had not been paralyzed, it was made a routine procedure. There is no evidence that the paralysis interferes with healing and there is experimental evidence that it does not decrease the tensile strength of the diaphragm.* Drainage of the pleural cavity was used in only three instances, once when the gangrenous colon was present, and twice when the hernia had been preceded by empyema. Water-seal drainage was used in these cases until the lung had fully re-expanded and obliterated the pleural space. Postoperative gastric suction was usually employed for a period of three days.




*A.* *B.*

Fig. 5.—L. S. *A*, A roentgenogram of chest five months after a penetrating chest wound. *B*, roentgenogram with barium meal showing hernia of the stomach that developed following physical exertion one year after the original injury. The constriction of the stomach by the defect is well demonstrated.

Maintenance of a clear airway by intratracheal aspiration was done as indicated if the patient was unable to keep his passages clear by his own efforts. In one patient in whom the phrenic nerve was not crushed, it was thought that the too vigorous application of this method produced such violent diaphragmatic contraction that rupture of the freshly repaired wound was produced as recurrence of the hernia was noted within four hours after the operation. Accordingly, after this experience the diaphragm was always paralyzed at the time of the operation, and greater caution was used in making the patient cough during the postoperative period.

### FINDINGS AT OPERATION

The organs herniated through the diaphragm are tabulated in Table II. In the simplest cases only the omentum protruded through the defect in the

*The Tensile Strength of the Paralyzed Diaphragm. Meade, Richard H., Jr.: J. THORACIC SURG. 2: 503, 1933.

diaphragm and was asymptomatic. The operations in such patients were done for other associated conditions. In four cases in which the liver was the herniating organ, only a presumptive preoperative diagnosis of diaphragmatic hernia was possible. Two of these have already been referred to as examples of an apparently slight injury to the diaphragm which later, after more than a year, allowed herniation of the liver. In one case, the incarceration of the stomach resulted in progressive distension until the entire left pleural space was filled. However, there was no impairment of the blood supply. The left lung was completely atelectatic. After enlarging the defect, it was possible to express the air from the stomach through the rubber tube inserted through the nose prior to operation. Separation of adhesions was then possible, allowing reduction of the hernia.

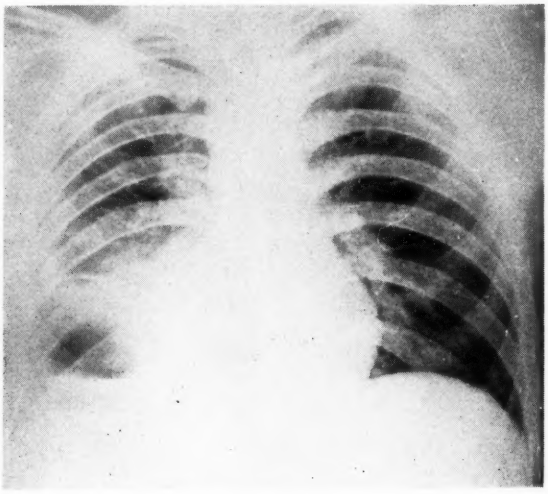


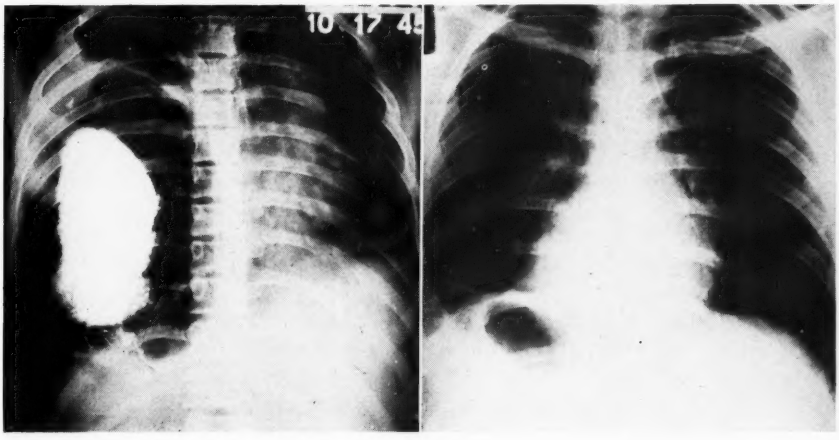
Fig. 6.—W. N. Roentgenogram of chest twelve hours following a jump from a truck. Herniation of the colon had occurred through a defect 1.5 cm. long. Approximately 15 cm. of gangrenous colon was resected and a double barrelled colostomy performed after the chest was closed with intercostal tube drainage connected to a water trap. Recovery from this operation and closure of colostomy was uneventful.

In only two of the entire series of hernias was a definite sac demonstrable. There often was a membrane covering a part of the herniated structure, but it was not complete. Adhesions between all structures were always present, but varied in extent and character. At times it was impossible to separate the herniated structures from the lung without some damage to it. The size of the opening in the diaphragm varied greatly from one of 1.5 cm. in diameter to one that involved the entire dome and extended into the pericardium.

The dome of the left diaphragm was the site most commonly involved, herniation through this area occurring in twelve cases. (Diagram 1.) The other sites were: right dome, three; right posteriorly, two; left posteriorly, two; left anterolaterally, two; left laterally, seven. The contusion defects are seen to be more peripheral and the penetrating defects more centrally located on the diaphragm.

Herniation of the colon through a defect 1.5 cm. long was followed by gangrene of the colon. The gangrenous portion of bowel was removed by cutting between clamps, and the two ends of the bowel covered with rubber glove and pushed out a left rectus incision. The defect was then repaired, the pleural cavity irrigated with saline, penicillin instilled, the lung expanded, and the pleural space drained by an intercostal tube connected to a water trap. A double-barrelled colostomy was then performed.

One large hernia was associated with an 8 cm. pericardial tear; another with herniation of the kidney, spleen, stomach, jejunum, ileum, colon, and omentum. These structures were densely adherent and completely covered the lateral portion of the diaphragm. A constricting ring defect around a herniated stomach was found in one case (Fig. 4). Had this progressed, it could have led to ischemic changes that would have been followed by perforation.



*A.* *B.*

Fig. 7.—H. F. *A*, Regional Hospital roentgenogram with the patient supine showing a greatly distended stomach partially filled with barium occupying the left pleural cavity. This Prisoner of War was injured in France in 1944, and had been working in this country for a year. The herniation followed carrying heavy sacks. *B*, postoperative roentgenogram. Recovery was uneventful.

In one instance, following a previous repair elsewhere, the diaphragm had been severed from its attachments to the posterior chest wall. A hydronephrotic, congenital, bifid kidney herniated through this defect. In this patient it was necessary to mobilize and remove the kidney before the diaphragm was repaired. Mattress sutures were passed through the diaphragm and chest wall to obtain a secure closure. Additional interrupted sutures were also employed between the diaphragm and intercostal muscles. The lung was collapsed to varying degrees, but in all instances re-expanded without difficulty. The length of time during which the collapse had been present seemed to make little difference in the ease with which re-expansion occurred. Although the chest was aspirated in two patients with herniated stomach and intestines, under the mistaken impression of pleural fluid, no harm resulted. At the time of the repair of the hernia, no evidence of infection or other damage was found.

## COMPLICATIONS

In one instance there was a rupture of the sutured diaphragm during the first day after operation. This was apparently due to the violent contractions of the unparalyzed diaphragm produced by vigorous use of intratracheal suction during the first few postoperative hours. The condition was promptly recognized and corrected. After this the diaphragm was paralyzed in each case except with small defects on the right side. In one patient in which the lung was damaged while separating it from the herniated liver, a pneumothorax developed which persisted for a short time. Pleural effusion of transient nature occurred three times and in one patient an empyema developed. This patient had previously had an empyema complicating the original injury that required treatment before the hernia could be repaired.

## SUMMARY

1. An analysis of twenty-eight traumatic diaphragmatic hernias that were repaired at the Kennedy General Hospital during the period from Jan. 1, 1944, to April 1, 1946, is presented. Sixteen of these were due to war wounds of the diaphragm, nine resulted from automobile accidents, two from falls, and one from a stab wound.

2. The right diaphragm was the site of hernia in five cases and the left in twenty-three.

3. Obstructive symptoms necessitated emergency operations in five cases.

4. Roentgenographic studies were diagnostic when hollow viscera were involved.

5. The diagnosis was not made until thoracotomy was performed in eight cases. These were instances in which the liver or omentum were the herniating structures.

6. Repair of the hernia was accomplished in every case through a transthoracic approach.

7. Endotracheal ether anesthesia was used in each instance except one.

8. The diaphragmatic repair was accomplished by means of two rows of interrupted silk sutures.

9. Paralysis of the diaphragm was induced in ten cases at the time of operation and was made a routine procedure.

10. Although excellent results were obtained in all patients before their discharge from the hospital, one immediate postoperative recurrence developed that was repaired later. Transient pleural effusion occurred in three patients, transient pneumothorax in one, and an empyema in another.

## CONCLUSION

Apparent slight injuries to the diaphragm may give rise to herniation at a later date. The medical profession should keep this fact in mind in dealing with veterans who have had wounds of their chest and with others who have had previous episodes of trauma, such as an automobile accident or a fall. Hernial repair was obtained in all cases presented. The transthoracic approach under endotracheal anesthesia allows optimum exposure.

# EXTRAPLEURAL PNEUMONOLYSIS WITH LUCITE PLOMBAGE

## A Preliminary Report

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### INTRODUCTION

During the past fifteen years we have seen a gradual improvement in the surgical treatment of pulmonary tuberculosis. There has been a definite lowering of the mortality and morbidity rates and a general improvement in the patient's prospect for the future. This advancement has been the result of improved anesthesia, operating, and operating room techniques, and the liberal use of blood, plasma, and prophylactic chemotherapy. The addition of pulmonary resection to the surgical management has been another step forward. Many who previously were considered hopeless are now given a favorable prognosis.

Despite this optimistic outlook, one still sees a great number of patients with stabilized pulmonary tuberculosis who cannot be managed by any of the present-day surgical methods of treatment; that is, patients with bilateral apical cavities, patients with low vital capacity, and patients of advanced age. For these patients we are constantly seeking new methods of treatment.

An approach to the solution of the problem has been extrapleural pneumonolysis and plombage. The advantages of this procedure have been pointed out by previous workers. It permits the selective collapse of the diseased lung and preserves the function of good lung tissue. It stabilizes the mediastinum and lessens the danger of bronchogenic spread. It preserves the normal chest structure.

The deterring factor which has prevented the successful utilization of this operation has been the lack of a solid material which can be molded to fit varying sized pockets and which can be left in the chest permanently without danger of harmful effects.

An attempt toward the experimental solution of this problem was begun in the fall of 1943, utilizing a plastic resin, methyl methacrylate, more commonly known by its trade names as Lucite, Plexiglass, Crystallite, Vitarilic, and others. This paper is a summary of the experimental studies and a preliminary report of the first fifteen patients in which this material has been used to maintain a surgical collapse of the lung for the treatment of pulmonary tuberculosis. The first patient was operated upon in July, 1945, and the fifteenth in December, 1945.

### HISTORICAL

Extrapleural pneumonolysis is one of the oldest operations in thoracic surgery. It was introduced by Tuffier in 1891.

From a surgical standpoint it is an attractive procedure utilizing skill and judgment. From a theoretical standpoint the operation is sound in that relaxation of the lung in a

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limited area or in all directions can be secured by extrapleural freeing of the lung. From a practical standpoint it has been most disappointing. The criticism has arisen not so much from the operative procedure as from the material which has been used to maintain the collapse.

Fat taken from the patient's subcutaneous tissue was first utilized by Tuffier in 1910. In his series of eleven cases there was only one cure, and there were four deaths.

Baer, in 1913, employed a paraffin mixture which hardened at body temperature and met the mechanical requirements better than fat. This material was used extensively in European hospitals by Sauerbruch, Nissen, and co-workers. In this country the operation never became popular, because complications which were difficult to manage frequently attended its use. Necrosis of thin-walled cavities and penetration of the free pleural cavity occurred. Severe infections were common.

Head as late as 1937, advocated the paraffin pack as a preliminary to thoracoplasty in the management of large apical cavities. He observed a higher percentage of favorable results than when thoracoplasty was performed as the initial operation. He attributed this fact to the lessened danger of contralateral spread as a result of diminution in size of the cavity and stabilization of the mediastinum prior to thoracoplasty. Twenty-four of the thirty-one patients in which this type of management was used had conversion of their sputum, three were improved, two were made worse, and two died. Perforation of the paraffin into the lung occurred in four patients.

Casper, Sauerbruch, Schlange, and Matson used plain gauze to fill the extrapleural space. In a preliminary report in 1938, Matson reported eighty-one patients in whom gauze had been used to maintain an extrapleural collapse. Conversion of sputum was secured in fifty-four patients. Only fifteen were considered clinically well with the pack removed. Infection occurred in eighteen patients, necessitating early removal of the gauze. There were four deaths, none directly attributed to the operation.

Archibald, Alexander, Churchill, Goffaerts and DeWinther, Sebrechts, and Shivers have advocated filling an extrapleural pocket with pectoral muscles detached from the chest wall and humerous. Archibald and Butler, Skinner, Douglas, and Merkel combined muscle packing with thoracoplasty. The disadvantages of these procedures were the increased operating time, the limited amount of muscle available for use, and the tendency of the muscles to atrophy.

The maintenance of an extrapleural space by means of air refills was first attributed to Mayer in 1913. In 1920, Rieckenberg and, in 1921, Jessen reported a small series of successful cases. In 1932, Jachia and Sebestyen advocated combining an extrapleural pneumothorax with an unsuccessful intrapleural pneumothorax. Between 1933 and 1938 an increasing number of cases was reported by Belsey, Graf, Nissen, Michelsson, Overholt and Tubbs, Schmidt, and Zorini. In 1939 Schmidt and his co-workers[4, 9, 24, 32] reported 544 cases with a good percentage of favorable results.

The use of extrapleural pneumothorax gained widespread popularity in this country between 1938 and 1940. This popularity, however, was short-lived. It soon became evident that air was not an ideal material to maintain an extrapleural collapse of the lung. The postoperative management was difficult. Refills were necessary at frequent intervals, and re-expansion of the lung failed to occur when treatment was discontinued. The space then had to be obliterated by means of a thoracoplasty or by filling with oil.

In 1940 Dolley, Jones, and Skillen reviewed the results of treatment of over 2,277 patients from twenty-seven clinics where extrapleural pneumothorax had been in use for more than two years. The results varied with the extent of the disease of the patients selected for operation. Conversion of the sputum was secured in only 53 per cent of the patients, and 11 per cent were dead. There was a high incidence of infection.

## EXPERIMENTAL STUDIES

Methyl methacrylate is a plastic manufactured from acetone, hydrogen cyanide, and methyl alcohol in the presence of sulphuric acid. The polymerized product is marketed in a clear solid form which softens at 105° C. and can

be molded easily into any desired shape. It is light in weight, has a tensile strength of from 6,000 to 9,000 lb. per square inch, and is not affected by weak acids or alkalies. It absorbs a negligible amount of water.

The use of methyl methacrylate in experimental animals to repair skull defects was first reported by Kleinschmidt in January, 1940. Prior to this time it had been used extensively in dental prosthesis and had been shown to be nonirritating when left in contact with mucous membrane for a long period of time.

In our studies[34] the methyl methacrylate in the form of small balls was inserted into the pleural cavity of thirty rats and into the extrapleural space of ten dogs. The animals were carefully observed, and x-rays of the chest were taken at frequent intervals. Autopsy was performed ten days to eight months after operation, and the tissues studied histologically.

The material was well tolerated by all of the experimental animals. X-rays revealed no excessive accumulation of fluid around the implants nor pneumonitis in the adjacent lung tissue. Empyema occurred in two of the rats.

The tissue reaction around the balls in the extrapleural space was similar to that observed by Kleinschmidt. During the first few days following operation, the implants were surrounded by a small amount of serum which rapidly clotted and became organized into a dense layer of hyaline connective tissue. Numerous eosinophiles were observed in the connective tissue during the first few weeks, but there were no foreign-body giant cells, even after eight months.

When implanted directly into the pleural cavity, the methyl methacrylate produced little effusion. In ten of the rats the pleura remained intact, and the methyl methacrylate balls were still free in the pleural cavity several months after operation. Histologic studies revealed some thickening of the pleura and infiltration of eosinophiles into the submesothelial region. The compressed lung showed varying degrees of atelectasis.

## CLINICAL STUDIES

In the beginning of this clinical work the author was convinced by the physical and chemical properties and from the animal experiments that methyl methacrylate fulfilled the qualifications of an ideal plombage material. It is inexpensive and readily available.* It can be molded into any desired shape prior to operation. It is of such light weight that a large quantity can be introduced into an extrapleural pocket without danger of penetrating the free pleural cavity or lung.

It is insoluble in the tissues and not subject to chemical change. It is nonirritating and causes no undesirable foreign-body reaction. It offers little resistance to x-rays and does not interfere with interpretation of chest films.

Since varying sized pockets were to be filled through relatively small incisions, methyl methacrylate in the form of a small ball was chosen as being most suitable for our purposes. As no commercial source was available at that time, these balls had to be manufactured in our own laboratory.

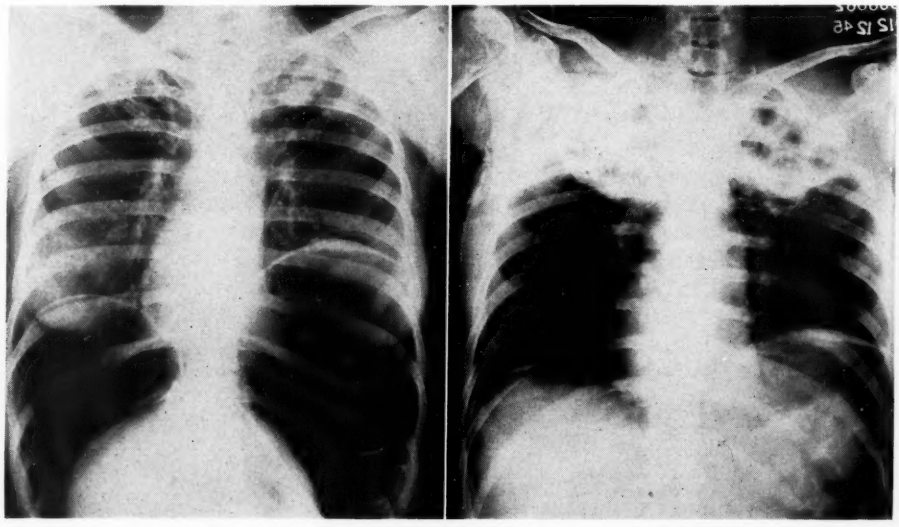
Two types were designed for clinical use, a solid ball of ¾ inch diameter and a hollow ball of one inch diameter. The solid balls weigh 4.5 Gm. each. They can be sterilized by boiling and do not interfere with interpretation of the chest x-rays. The hollow balls weigh 3 Gm. each and must be sterilized chemically. In the x-ray they appear as regular, circular shadows with a center of decreased density. This makes the x-ray differ-

*The methyl methacrylate balls are now being manufactured by Nichols Products Company, 325 West Main Street, Moorestown, N. J.

entiation from a pulmonary cavity difficult on plain films; however, they can be distinguished easily on laminographic films. In spite of these relative disadvantages, the hollow balls have proved most applicable to clinical use due to their light weight.

The methyl methacrylate was first made into the shape of half spheres. These were stored in a 1:1,000 aqueous solution of Zephiran Chloride. Forty-eight hours prior to operation the half-spheres were removed from the zephiran solution under sterile precautions, dried, and under bactericidal radiation sealed together, using ethylene dichloride as the softening agent. This technique insured sterility of the air within the ball as well as the ball itself. After a few minutes during which the seal was allowed to dry, the balls were again immersed in the zephiran chloride solution to remain until used.

The average number of balls used per person was thirty. The smallest number used was fifteen, and the largest number was sixty.



*A.* *B.*

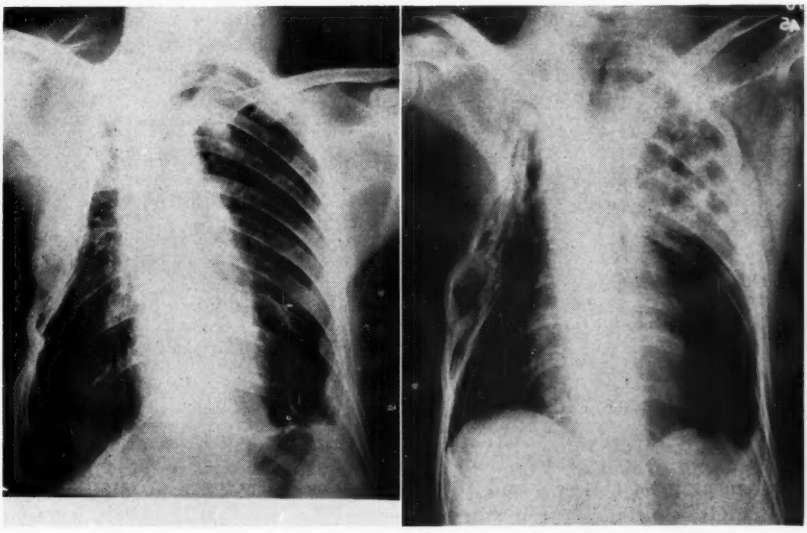
Fig. 1.—*A*, X-ray of chest of patient (Case 11) showing bilateral apical cavities. *B*, After bilateral apicolysis.

In the selection of patients for operation no hard and fast rules have been established. The indications will, undoubtedly, vary with the experience gained by the clinical use of this material. All of the patients had been under sanatorium care and had shown some resistance to the disease process; therefore, recent spread did not constitute the same contraindication as for thoracoplasty. All of the patients had had pneumothorax attempted, and all had been bronchoscoped to rule out stenosis of the bronchus.

In the early phase of this clinical work the author was primarily concerned with the treatment of those so-called good chronic patients in whom thoracoplasty was contraindicated because of their low vital capacity, advanced age, or bilateral cavities, and with the treatment of those patients who had had an unsuccessful thoracoplasty. As experience has been gained in the use of the methyl methacrylate balls, the clinical application has been broadened to include borderline patients who, ordinarily, might have been considered suitable for thoracoplasty.

In twelve of the fifteen patients extrapleural pneumonolysis was performed in the apical region through an anterior incision. Preoperatively, the patient is given 0.1 Gm. of sodium pentobarbital and 10 mg. of morphine. The skin is infiltrated with 2 per cent solution of procaine. The incision is made parallel to and overlying the second rib and

cartilage. The intercostal nerves are blocked with 2 per cent procaine, and a 4-inch segment of rib and cartilage resected by an aperiosteal dissection. The resected rib segment is carefully saved. An incision is made through the posterior periosteum, and the extrapleural space is carefully developed by blunt dissection. Special instruments are not necessary for the successful completion of this stage of the operation. Finger dissection first, then dissection with a small sponge on a clamp as the space is enlarged, is much safer than instrumental dissection. Freeing of the mediastinal pleura is usually accomplished without difficulty. Dense adhesions attached to the apex or lateral chest wall are best completely isolated and divided by sharp dissection close to their attachment to the rib, or more safely by removal of the adjacent periosteum. If isolated adhesions are so densely adherent to major vessels or nerves that they make division seem unwise, they may be left undivided without necessarily interfering with the successful completion of the operation, since compression can be secured on all sides by packing around the isolated segment of the lung. Local anesthesia is rarely required after the extrapleural space is entered. The patient experiences little discomfort except for some mild paroxysmal coughing when the mediastinal pleura is freed.



*A.* *B.*

Fig. 2.—*A*, X-ray of chest of patient (Case 9), showing thoracoplasty on right side and cavity in the left apex. *B*, Postoperative x-ray of the same patient.

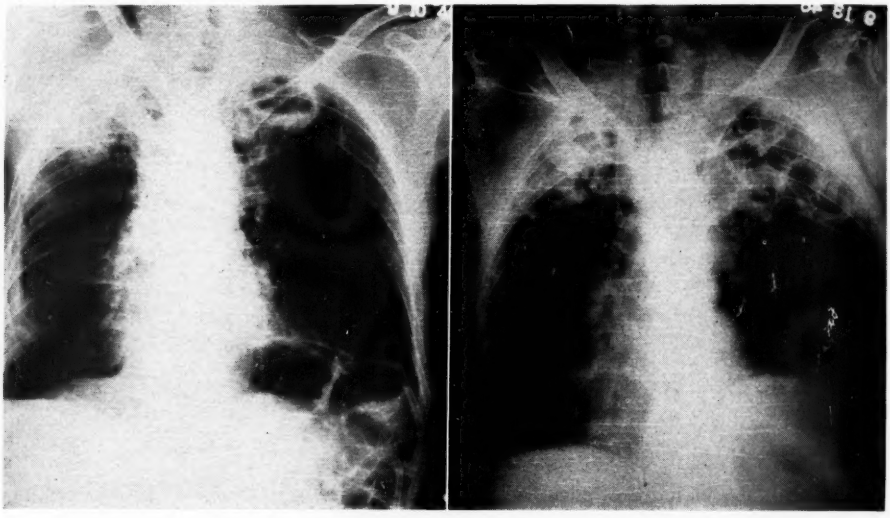
When the dissection has proceeded to the desired extent, the space is filled with methyl methacrylate balls. The desired degree of compression can be secured by having the patient expire while filling the pocket without tension. The balls are held within the extrapleural space by suturing the segment of rib into its original position and approximating the periosteum around it. One hundred thousand units of penicillin are injected into the extrapleural space, and closure is performed. The pectoral muscles are carefully reapproximated and sutured to the periosteum of the rib to prevent elevation of the incision by the fluid which accumulates in the extrapleural space postoperatively.

Eight of the patients on whom apicolysis has been performed had bilateral pulmonary involvement.

Two patients (Cases 11 and 14) had cavities in both apices. Bilateral apicolysis and packing with methyl methacrylate balls was performed in stages

two and three weeks apart. One patient has had a negative sputum since operation. (Fig. 1.)

Two patients (Cases 5 and 9) had apical cavities with a contralateral thoracoplasty. Both withstood apicolysis successfully. One patient complained of dyspnea for several weeks following operation, but this has gradually disappeared. His weight and general condition have improved, and his sputum is now negative. Sputum in the other patient has diminished greatly but is still positive. (Fig. 2.)



*A.* *B.*

Fig. 3.—*A*, X-ray of chest of patient (Case 4) showing large thin-walled cavity in the left apex and infiltration in right apex. *B*, Postoperative x-ray showing collapse of the left apex with hollow methyl methacrylate balls.

Two patients (Cases 4 and 13) had cavities in the apex of one lung with dense infiltration and scarring in the apex of the other lung. Apicolysis and packing with methyl methacrylate balls was performed on the side of the cavity in both patients. One patient has had a negative sputum since operation. (Fig. 3.) This patient had a 4 cm. thin-walled cavity which at the time of operation could be depressed with ease by the operator. A ball was placed in this depression at operation maintaining the sides of the cavity in apposition. The other patient has had only one positive sputum in four examinations since operation.

A 31-year-old white woman (Case 6) was admitted for extrapleural apicolysis because low vital capacity contraindicated thoracoplasty. She gave a history of pulmonary tuberculosis of eleven years' duration. Pneumothorax, phrenic crush, and pneumoperitoneum had been tried without success. Her vital capacity on admission was 900 c.c. Extrapleural apicolysis was performed without difficulty. The entire apex was stripped free from the chest wall and packed against the mediastinum with twenty-two hollow balls. She complained of some increased dyspnea immediately following operation, and quantity of sputum

was greatly increased. At the present time her general condition is greatly improved. There is little or no sputum. The vital capacity is 750 c.c.

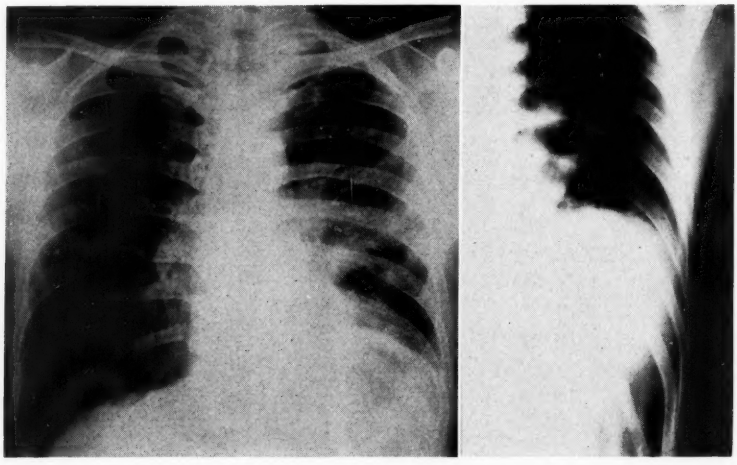
A 50-year-old white man (Case 7) was admitted to the hospital for treatment of a cavity in the left lower lobe near the costovertebral angle. (Fig. 4.) He gave a history of asthma of thirty years' duration and pulmonary tuberculosis of six years' duration. Pneumothorax, phrenic crush, and pneumoperitoneum had been tried without successful closure of the cavity. Vital capacity was 2,550 c.c. prior to operation. Extrapleural pneumonolysis was performed through an incision overlying the ninth rib in the posterior axillary line. Dissection was found to be easier in this area than in the apex of other patients due to the presence of fat located in the extrapleural space. The pleura in the region of the cavity was greatly thickened. After the entire lower lobe had been mobilized, the space was filled with sixty hollow balls. The segment of rib was resutured into place in the usual manner, and the incision closed. The postoperative course was uneventful. He was discharged to return to the sanatorium on the tenth postoperative day. The vital capacity at that time was 1,975 c.c. At present the patient has no cough and only a small amount of early morning sputum which has been intermittently positive for acid-fast organisms since operation.

The average age of the patients operated upon was 42. The youngest was 25, and the oldest 59 years of age. This latter patient (Case 15) was admitted with a history of pulmonary tuberculosis of two years' duration. She had a 4 cm. cavity in the right apex which had been treated unsuccessfully with pneumothorax, phrenic crush, and pneumoperitoneum. Extrapleural apicolysis with mobilization of the entire apex and packing with twenty-seven hollow balls was performed on December 20, 1945. Her sputum is still positive for acid-fast organisms but has diminished from one-half cup per day to little or none.

Four of the patients on whom apicolysis and packing with methyl methacrylate balls was performed had had a thoracoplasty on the side of operation. One patient (Case 1) had had a bilateral thoracoplasty, and three of the patients (cases 2, 3, and 12) had had an extrafascial apicolysis performed at the time of thoracoplasty. Dissection in these cases was only slightly more difficult than in those patients on whom no previous operation had been performed. In only one case did extrapleural dissection prove too difficult through an anterior approach and have to be abandoned. This patient (Case 8) was later dealt with through a posterior approach, combining packing with a modified two-stage revision thoracoplasty.

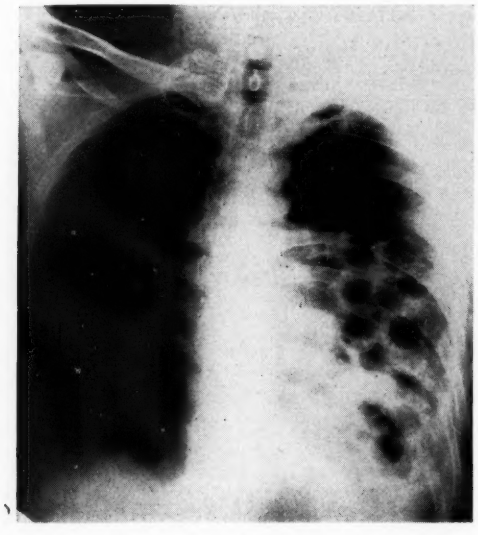
Patients with uncollapsed cavities beneath a thoracoplasty constitute a group in which this procedure would appear to be indicated instead of a revision thoracoplasty. Many of these patients have cavities which are located in the costovertebral angle or anteriorly where successful closure by complete costectomy is unlikely. Extrapleural apicolysis and packing offers these patients a single-stage operation which can be performed under local anesthesia with little or no shock. It permits localized compression of the involved area of the lung.

During recent years more and more attention has been called to the need for some method to maintain a collapse of the apex between the stages of a thoracoplasty. The experience of many surgeons has been the occurrence of a negative sputum immediately after the first stage with a return to positive before the second stage. The extrafascial apicolysis, which is frequently performed with the first stage, creates a pocket similar to that developed by



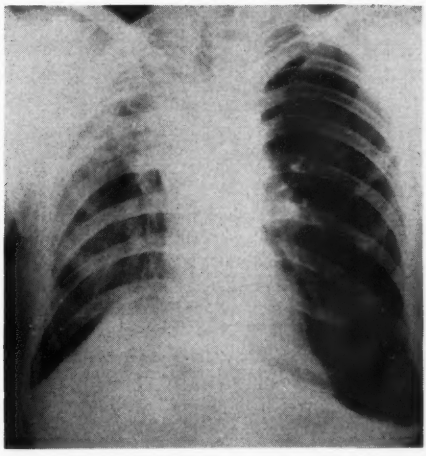
*A.* *B.*

Fig. 4*A*.—X-ray of the chest of patient (Case 7).
Fig. 4*B*.—Cavity is demonstrated by laminographic x-rays 5 cm. from posterior chest wall.



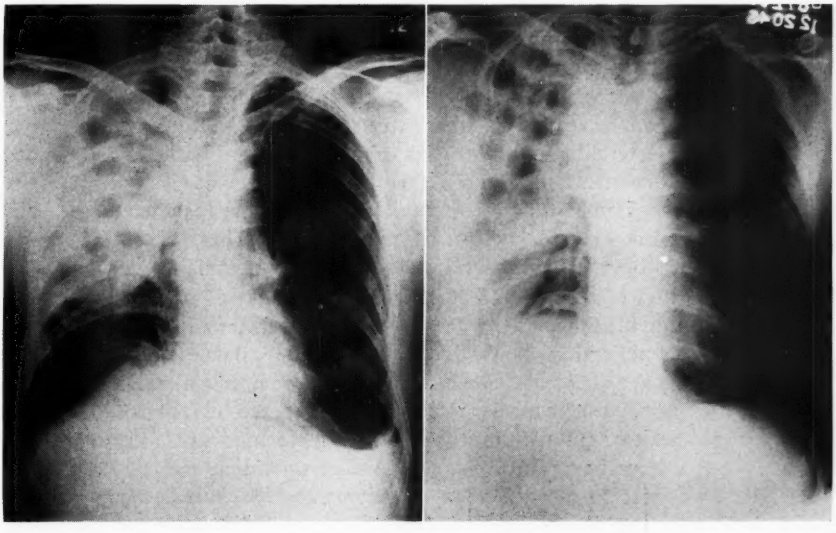
*C.*

Fig. 4*C*.—Postoperative x-ray showing collapse of left lower lobe by sixty hollow methyl methacrylate balls.



*A.*

Fig. 5*A*.—X-ray of chest of patient (Case 10) before operation.



*B.* *C.*

Fig. 5*B*.—X-ray of same patient after modified first stage thoracoplasty, apicolysis, and packing with hollow methyl methacrylate balls. The third and fourth ribs have been removed.

Fig. 5*C*.—X-ray of same patient after second stage thoracoplasty.

extrapleural apicolysis. This space contains air and fluid immediately after operation, and re-expansion occurs rapidly as the air is absorbed. The filling of this space with a rigid material, such as methyl methacrylate, would not only prevent re-expansion of the apex but would also prevent mediastinal shifting and lessen the danger of bronchogenic spread.

One patient (Case 10), a 42-year-old white man, has been operated upon with these considerations in mind. (Fig. 5.) This patient was first admitted to the Eastern North Carolina Sanatorium in September, 1944, with far-advanced bilateral tuberculosis. Pneumothorax was instituted on the right but had to be discontinued due to adhesions and the formation of a pleural effusion. A right phrenic crush was performed in September, 1944, and in January, 1945, pneumothorax was started on the left side. At the time of admission to Duke Hospital in November, 1945, fluoroscopy of the chest revealed multiple cavities in the right apex, paralysis of the right side of the diaphragm, and a successful pneumothorax on the left side. On Nov. 30, 1945, a modified first-stage thoracoplasty was performed on the right side. The third and fourth ribs were removed, and an apicolysis was performed. The first and second ribs were left in place to protect the brachial plexus and vessels. The pocket was then filled with forty-eight hollow methyl methacrylate balls holding the apex of the lung below the fifth rib posteriorly. Closure of the wound was performed in the usual manner with the balls being held in position by the scapula and the weight of the shoulder. He complained of moderate pain but had no difficulty in breathing or raising sputum. The sputum remained positive for acid-fast organisms, and on December 18 a second-stage procedure was performed with removal of the fifth, sixth, and seventh ribs and transverse processes. The balls maintaining the apical collapse were left undisturbed. His postoperative course was uneventful. Sputum has been negative since the second stage. Pneumothorax is still being maintained on the left side. The vital capacity was reduced from 2,300 c.c. to 1,400 c.c.

## POSTOPERATIVE COURSE AND COMPLICATIONS

The postoperative management of the patients following packing with methyl methacrylate balls was relatively easy. All of the patients complained of a moderate amount of pain and a feeling of pressure in the operative site for several days. Two of the patients noticed the clicking together of the balls in the chest, and one complained of difficulty in swallowing. These symptoms completely disappeared within the first two or three weeks.

The reduction of vital capacity varied with the extent of the pneumonolysis and the individual patient. The average reduction was 400 c.c. Two of the patients complained of marked dyspnea. One patient (Case 6), with a preoperative vital capacity of 900 c.c., has gradually improved and is now quite comfortable with a vital capacity of 750 c.c. The second patient (Case 3), a 47-year-old white man with a complicating asthma, died suddenly on the eighth postoperative day. Vital capacity before operation was 1,100 c.c. On the sixth postoperative day the vital capacity was 800 c.c. Autopsy revealed marked dilatation of the right side of the heart and diffuse scarring of both lungs. Death was attributed to cardiac failure as a result of diminished pulmonary circulatory bed.

The average maximum postoperative temperature elevation was 38° C. usually occurring on the second or third postoperative day and returning to normal by the seventh postoperative day. Two patients had temperature elevations of 39° C., with a gradual decline to normal by the tenth postoperative day. Four patients had a temperature of less than 37.5° C. postoperatively.

One patient (Case 2) developed a small superficial hematoma which was drained by spreading the incision and which healed promptly. There were no infections in this series of patients.

All patients were operated upon in rooms equipped with bactericidal ultraviolet radiation[12] and were given penicillin postoperatively, for ten days. The author feels that these precautions contributed to the benign postoperative course of the patients and the absence of infections.

Excessive accumulation of fluid around the balls postoperatively was not a problem. In only one patient (Case 2) was the accumulation of fluid beneath the incision sufficient to warrant aspiration. This complication was avoided in subsequent cases by a careful approximation of the tissue planes during closure.

A generalized urticaria accompanied by an increase in the circulating eosinophiles developed in one patient (Case 1) on the tenth postoperative day. This patient had no history of allergic phenomena, and the differential blood count, preoperatively, was normal. A careful investigation of this patient revealed no evidence of sensitivity to the usual allergens. Symptoms rapidly subsided, and there has been no recurrence. This reaction led us to make daily differential white blood counts, postoperatively, on all patients in which methyl methacrylate was used. Four other patients were noted to develop an eosinophilia of 6 to 10 per cent between the seventh and tenth postoperative days. Examination of the fibrinous clot around the plastic balls removed at autopsy on Case 3 also revealed a preponderance of eosinophiles. This patient had a history of asthma prior to operation but showed no postoperative eosinophilia.

The mechanism of this response is being studied. Attention is called to the experimental studies of Spealman, Main, Haag, and Larson, in which mild sensitivity was noted in 20 per cent of subjects following local application of monomeric methyl methacrylate. No sensitivity was noted when the polymeric form was used locally or when implanted into the animals.

## SUMMARY AND RESULTS

This paper is a preliminary report on the first fifteen patients in which an acrylic resin, methyl methacrylate, has been utilized to maintain a collapse of the lung for the treatment of pulmonary tuberculosis.

All of the patients were operated upon between July and December, 1945. All may be classified in the group of so-called good chronic patients, who have had an unsuccessful thoracoplasty, or who, because of their low vital capacity, advanced age, bilateral disease, and other complications, were unsuitable for thoracoplasty.

Thirteen of the patients have been improved by the operation; one has shown no improvement; and one is dead. Of the thirteen that have been improved, six have had negative sputum since operation.

The postoperative management of these patients was relatively easy. There were no infections. One patient developed a generalized urticaria on the tenth postoperative day, and four other patients were noted to have an increase in the circulating eosinophiles between the seventh and tenth postoperative days. One patient died on the eighth postoperative day with cardiac failure due to diminished pulmonary circulatory bed.

The author recognizes the fact that too few cases have been completed and that too short a period of time has elapsed since operation to evaluate the results of this form of collapse therapy; however, he feels that the experimental and clinical results so far warrant the continued use of this material. It adds to the surgeon's armamentarium a single-stage operation which can be used successfully in the treatment of patients not suitable for either thoracoplasty or resection. An evaluation of this operation will depend upon experience gained through its continued use.

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# EPIDURAL ANESTHESIA IN THORACIC SURGERY

## A Preliminary Report

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THORACIC physicians and surgeons in this country have taken advantage of recent advances in anatomic and physiologic knowledge pertaining to the lung and chest. However, they have failed to match this technical improvement with a corresponding advance in thoracic anesthesia. We are presenting, for the first time in this country, a report on a series of 100 cases of thoracic operations performed between October, 1945, and September, 1946, with epidural anesthesia. This anesthetic is being presented for consideration as an anesthesia which gives the operator a wide-awake and cooperative patient who is able to follow the surgeon's instructions during the operation. For example, he is a patient who can cough and raise sputum as indicated, thus reducing the incidence of postoperative spread of the disease process or of atelectasis. Further advantages of this type of spinal anesthesia are brought out in this paper.

The anesthesia is accomplished by injecting the anesthetic agent into the epidural space which lies between the dura mater of the spinal cord and the bony and fibrocartilaginous boundary of the vertebral canal.

The higher epidural, as distinguished from the caudal, which is a low form of epidural anesthesia, was first successfully used by Fidel Pages[1] of Spain in 1920, when he reported its use in forty-three cases of abdominal surgery. After his premature death, unfortunately, the subject was lost in obscurity until the reports by Dogliotti[2] of Italy and Gutierrez[3] of Argentina in 1932. Since that time, epidural anesthesia has been widely used in Europe and South America.

Very little mention of epidural anesthesia in thoracic surgery may be found in the English literature until 1941, when Rees and Abajian[4] stated it could not be used successfully in first stage thoracoplasties, but could be used in subsequent stages. In 1944, Vasconcelos[5] of Brazil, in reporting on esophagectomy for carcinoma of the esophagus, stated he has used epidural anesthesias for thoracoplasties, pneumonectomies, and lobectomies as well as for five total esophagectomies, and is convinced that it is the anesthetic of choice. In the section of Anesthesiology of the Proceedings of the Royal Society of Medicine for 1945, mention is made of Dawkins[6] of England now using epidural anesthesia for all his thoracic surgical cases.

### ANATOMY AND PHYSIOLOGY

In order that the technique of administering and effecting this anesthesia be clearly understood, let us briefly consider the anatomy of the areas concerned.

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In the vertebral canal, we have from within outward (Fig. 1):

A. The spinal cord with its anterior and posterior roots
B. The pia mater, closely investing the spinal cord
C. The subarachnoid space, where the usual spinal anesthesia is given
D. The medullary layer of the dura mater, which lies adjacent to the arachnoid. A potential space exists between these two membranes, which is the subdural "space."
E. The epidural space lying between the dura mater and the membrane lining the vertebral canal.

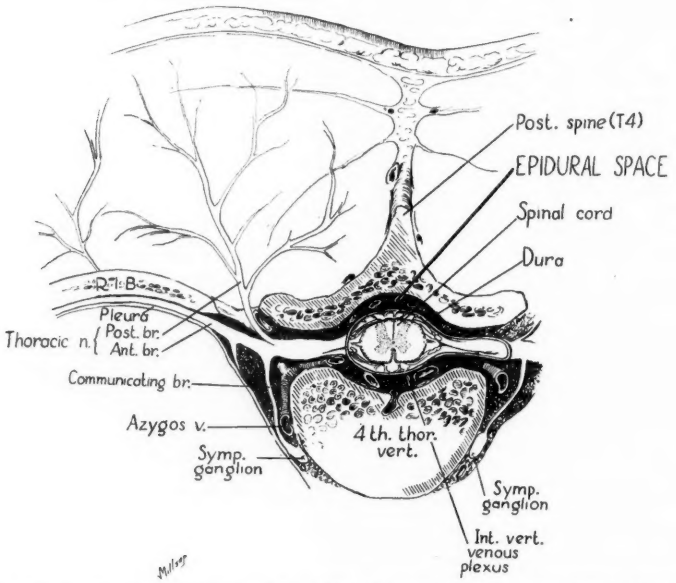


Fig. 1.—Illustrating the continuity of the epidural space with the paravertebral structures.

It is important to note that this epidural space is closed above at the foramen magnum by the fusion of the lining of the vertebral canal and the dura mater, that it extends the full length of the vertebral canal, and that it is closed at the sacrococcygeal juncture (Figs. 2 and 3). Laterally, this space communicates with the paravertebral tissue wherein lie the roots of the spinal nerves and the sympathetic ganglia with their gray and white rami communicantes. These ganglia extend from the first thoracic to the second lumbar segments.

The epidural space contains loose adipose and areolar tissue, venous and arterial plexus, and lymphatic vessels.

In 1927, Heldt and Moloney[7] found that a negative pressure of from minus one to minus 18 mm. of mercury exists in the epidural space. Bonniot,[8] in 1934, found that this negative pressure could be greatly increased by kyphosing the patient and flexing his neck. Gutierrez,[9] in 1932, first utilized

this negative pressure in locating the epidural space by placing a drop of fluid in the hub of the needle, and slowly advancing the needle until the drop was sucked in. This is called Gutierrez' "drop sign."

The anesthesia is predominantly sensory. Thus, we have no impairment of the intercostal muscles, diaphragm, nor the accessory muscles of respiration. Dogliotti[2] has shown that little if any penetration of fluids and dyes takes place through the dura. The anesthetic in the epidural space thus cannot reach the subarachnoid space, nor can it reach the vital centers in the medulla,

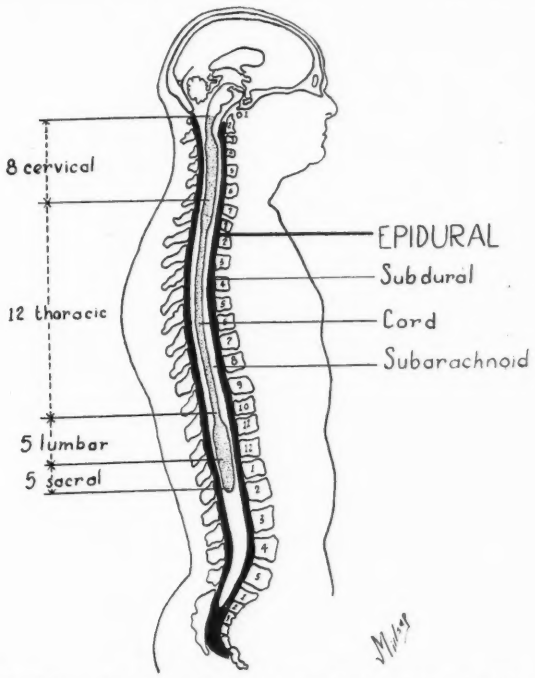


Fig. 2.—Schematic drawing illustrating the limits of the epidural space.

as it will be remembered the space is closed at the foramen magnum. The anesthetic solution can escape the vertebral canal only through the intervertebral foramina, where it bathes the spinal nerves and the sympathetic chain in the paravertebral tissue. The anesthesia is induced in the region of and lateral to the intervertebral foramina, where the medullary layer of the dura fuses with the perineurium of the spinal nerves. Dawkins[6] explains the sensory selectivity of the anesthesia as due to the relative large sizes of the motor nerves (2 to 20 micra) as contrasted to the smaller sizes of the sensory and sympathetic fibers (one-half to 2 micra); the anesthetic agent penetrating the smaller nerve fibrils with greater ease. This barrier to the anesthetic may be due to the medullary sheaths surrounding the larger nerves (Ranson[10]). Galley[6] thought it highly suggestive that the facility with which the neurones were

paralyzed corresponded closely with the size of the fibers, which in turn was largely determined by the degree of medullation. He further states that all the pain fibers are small and nonmedullated and are the most easily blocked, whereas the motor fibers have thick medullary sheaths and are least affected.

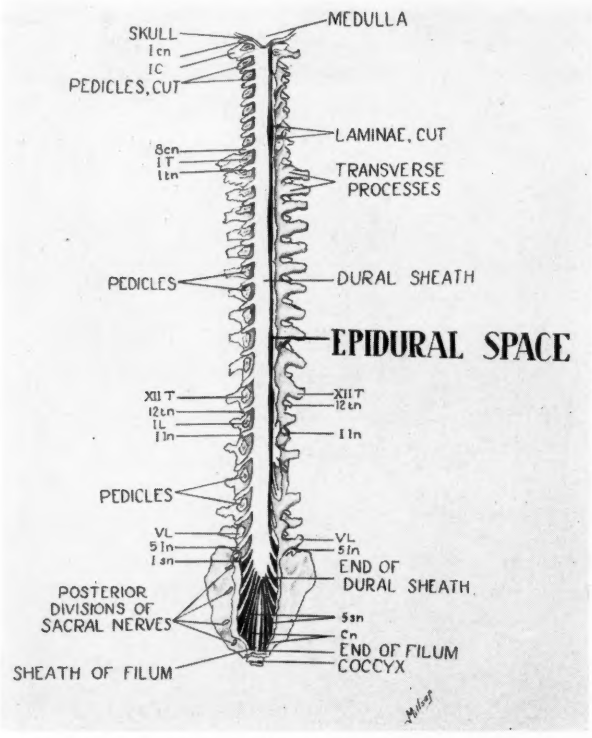


Fig. 3.—Posterior view of epidural space with lamina removed.

TECHNIQUE OF ADMINISTRATION

No special equipment is necessary for performing an epidural anesthesia. Special needles have been designed by Gutierrez, and various indicators for demonstrating the negative pressure in the epidural space have been recommended[11, 12] but we believe they are not necessary. The epidural tray consists of the following materials (Fig. 4):

One 10 c.c. syringe

Two 2 oz. medicine glasses or beakers, one containing physiological saline and the other for mixing the anesthetic

Twenty-five g. short hypodermic needle

Sharp 18 g. needle or a pointed B-P knife blade

Eighteen to 20 g. regular short bevel spinal needle

Ampules of novocaine and pontocaine

Adrenalin ampule

File.

We have used various concentrations of procaine (from one to 2 per cent), procaine-pontocaine mixtures, all with and without adrenalin. We also used 1½ per cent Metycaine on one occasion. For operations lasting up to 1½ hours, we now use the following mixture: 500 mg. procaine crystals, 20 mg. pontocaine ampule, 0.5 c.c. 1:1,000 adrenalin, in 40 c.c. physiological saline. If an operative procedure is expected to last over two hours, we use 600 mg. procaine and 40 mg. pontocaine with 0.5 c.c. adrenalin in 40 c.c. saline. With these amounts, we have found the anesthesia to extend over eight to ten spinal segments.

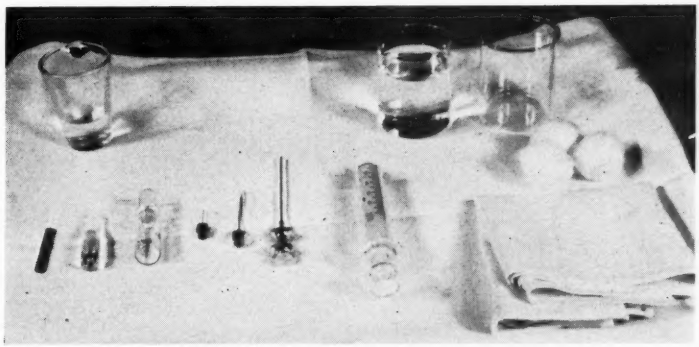

Fig. 4.—Epidural tray. The medicine glass on the left contains 1 per cent procaine for infiltrating the skin. Adrenalin is not shown on the tray, as in our clinic the nurse instills the adrenalin into the anesthetic solution.

To allay fear and apprehension, all patients receive a barbiturate (sodium Amytal gr.iii) the night before operation. They are given 1½ to 4½ grains of Nembutal one and one-half hours before and morphine sulfate gr. ⅛ to ⅙ with 1/300 atropine sulfate forty-five minutes before surgery. The anesthetic solution is prepared after the patient arrives in the operating room.

The site of the puncture is chosen in an interspace in an area between the seventh cervical and the third thoracic spines. As gravitation aids in the downward diffusion of the solution, we prefer to administer the anesthetic with the patient sitting with his back bowed and head flexed. The assistant supports the patient securely in this position (Figs. 5 and 6).

After the anesthetic has been prepared and the site of puncture painted with antiseptic solution, a wheal is made exactly in the midline in the depression between the spinous processes. A small nick is made with the larger needle or knife blade in order that the short-bevelled spinal needle may be more easily introduced. The spinal needle, with the stylet in situ, is then introduced in the midline, paralleling the spinous processes of the interspace selected. One will quickly learn to recognize the various structures the needle

penetrates by the differences in resistance. There is moderate resistance in penetrating the supraspinous ligament, slight in the interspinous ligament, and a rather marked resistance when the point of the needle meets the tough ligamentum flavum. At this point the stylet is removed and a drop of saline is placed in the hub of the needle. The needle is then very slowly advanced. When the ligamentum flavum is penetrated, a sudden "give" is experienced and at the same time the drop of saline will be sucked inward. Not infrequently a definite hissing sound is heard as the air is sucked into the epidural space.

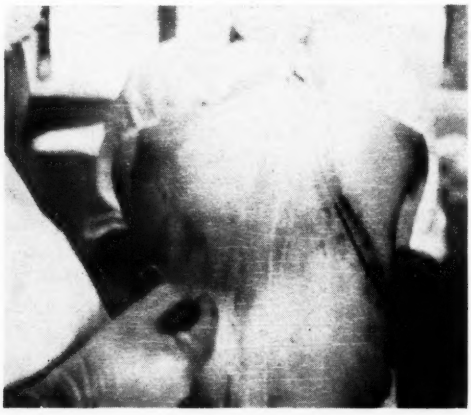

Fig. 5.—Showing how the assistant supports the patient.

With the syringe we then attempt to aspirate any spinal fluid or blood. A few cubic centimeters of air may be injected very easily as a further test, if one is within the space. If these various maneuvers satisfy us that we are within the epidural space, 10 c.c. of the solution is then injected, taking from ten to fifteen seconds. At this time, we give the patient ⅜ to ¾ grain ephedrine sulfate or an equivalent of Methedrine by hypodermic. This is done at this time rather than earlier in order to avoid giving the ephedrine or Methedrine to one in which epidural anesthetic might be abandoned.

Earlier in our series, we waited three to five minutes, then tested the patient to see that a subarachnoid injection had not been made; a waiting period recommended by most of the various authors. Later, if we were confident of the position of the needle, this waiting period was eliminated. The remainder of the anesthetic was given at the same rate of ten to fifteen seconds for each 10 c.c.

After the administration, the patient was placed on the table with his operative side down for ten minutes in order to take further advantage of the dependent gravitation of the fluid.

Earlier in our series, if spinal fluid or blood were aspirated, the anesthetic was abandoned. Later another and even a third attempt in the adjacent interspaces either above or below was made in such instances.

## OBSERVATIONS

The time consumed in the administration of the anesthetic varied from two to twelve minutes, averaging three and one-half minutes. The average time between the completion of the anesthetic and the beginning of the operative procedure was twenty-seven minutes; ten minutes of this time being consumed by the patient lying on his operative side, and the remainder in preparing the field and draping.

**Fig. 6.**—Demonstrating the angle at which the needle is introduced.

We have used epidural anesthesia in 100 thoracic operations on sixty-six patients (Table I). The youngest was a 16-year-old girl who underwent a thoracoplasty and the oldest a 65-year-old man who underwent a pneumonectomy for bronchogenic carcinoma. Their diagnoses and operative procedures are tabulated in Tables II and III. In addition, there were five other patients in whom the anesthetic was abandoned. In three of these cases spinal fluid was obtained and blood was aspirated in the other two.

The drop sign was used as a guide in locating the epidural space. In the first fifty cases, it was present in forty-six (92 per cent). In the second fifty cases, it was present in 100 per cent. Ruiz,[11] working in Gutierrez' clinic, reported a positive drop sign on 84 per cent of 415 gynecologic cases, where the injection was performed in the second lumbar interspace. We believe that when the technique is carried out correctly in the high dorsal region, the drop sign should be present in all cases.

The anesthesia has been classified under four categories: (1) excellent, absolutely no discomfort; (2) good, slight discomfort, not enough to warrant supplementary anesthesia; (3) fair, when supplementary anesthesia was used during *part* of the operation; (4) poor, when some other anesthetic was necessary throughout the operation. These results together with their relationship to the presence or absence of the drop sign are tabulated in Table IV. It will

TABLE I. 100 EPIDURAL ANESTHETICS, 66 PATIENTS

| SEX | AGE GROUPS 16-20 | 20-40 | 40-60 | 60-65 | TOTAL |
|---|---|---|---|---|---|
| Male | 0 | 13 | 13 | 4 | 30 |
| Female | 5 | 27 | 4 | 0 | 36 |

TABLE II. DIAGNOSES

| DIAGNOSIS | NO. PATIENTS |
|---|---|
| Pulmonary tuberculosis | 39 |
| Tuberculous bronchiectasis | 3 |
| Tuberculous bronchitis with stricture | 4 |
| Tuberculous empyema | 4 |
| Bronchiectasis (nontuberculous) | 6 |
| Lung abscess | 4 |
| Bronchogenic carcinoma | 4 |
| Exploratory, possible lung tumor | 2 |
| Total | 66 |

TABLE III. OPERATIONS

| OPERATIONS | NO. |
|---|---|
| Thoracoplasties (including 7 scapulectomies and 2 apicolyses) | |
| First Stage | 32 |
| Second Stage | 25 |
| Third Stage | 18 |
| Pulmonary Resections | |
| Lobectomy | 6 |
| Pneumonectomy | 9 |
| Exploratory thoracotomy | 4 |
| Rib resection and drainage | 4 |
| Secondary closure of bronchus | 2 |
| Total | 100 |

TABLE IV

A—DROP SIGN

| GROUP | PRESENT | ABSENT |
|---|---|---|
| First 50 patients | 46 (92%) | 4 (8%) |
| Second 50 patients | 50 (100%) | 0 |
| Total | 96 | 4 |

B—ANALYSIS OF ANESTHETIC AND RELATION TO DROP SIGN

| GROUP | EXCELLENT | GOOD | FAIR | POOR |
|---|---|---|---|---|
| First 50 | 31—all Drop Sign | 13—12 Drop Sign | 4—2 Drop Sign | 2—1 Drop Sign |
| Second 50 | 45—all Drop Sign | 3—all Drop Sign | 1— | 1— |
| Total | 76—all Drop Sign | 16—15 Drop Sign | 5—3 Drop Sign | 3—2 Drop Sign |

100 cases—Drop Sign present in 96 (96%)

TABLE V. ANALYSIS OF FAIR AND POOR CASES

A. FAIR CASES (5)

1. Metycaine used. No drop sign. 50 to 60 per cent nitrous oxide analgesia throughout
2. Turned 10 minutes on opposite side. Drop sign present. Ten cubic centimeters ½ per cent procaine used in making incision.
3. Drop sign absent. 90 per cent nitrous oxide given twenty minutes at beginning
4. Drop sign present. 90 per cent nitrous oxide given fifteen minutes to allay nervousness
5. No pontocaine used. 85 per cent nitrous oxide analgesia twenty-two minutes during removal of ribs.

B. POOR CASES (3)

1. No drop sign
2. Drop sign present. By error, 30 c.c. saline given, followed by 45 c.c. anesthetic
3. After injection of one-half of solution, patient complained of dyspnea with wheezing, which disappeared in a few minutes. Anesthetic abandoned.

be noted that there were five cases in which the anesthetic was considered fair; four of these occurred in our first group of fifty. There were three cases in which the anesthetic was considered poor; two of these occurred in our first group of fifty. Analysis of the poor and fair cases is listed in Table V. This last patient who complained of dyspnea and wheezing was later found to be quite allergic to pontocaine by skin testing.

One patient complained of nausea during surgery, but there were no cases of vomiting on the operating table. In one patient, a 62-year-old male who was considered a desperate risk and who underwent an exploratory thoracotomy, the blood pressure dropped to zero and pulse and respirations ceased. He responded to stimulants, oxygen inhalation, and artificial respiration within a few minutes and the operative procedure was continued. Frequently, patients complain of dizziness during the administration of the anesthetic, especially if the anesthetic is injected too rapidly. This is probably caused by transmission of the increased pressure in the epidural space through the dura and arachnoid to the cerebrospinal fluid. The dizziness quickly passes on after completion of the procedure.

During the operative procedure, other than for the psychic aspect, the patients were quite comfortable and able to converse with the operator. They were encouraged to cough and expectorate when necessary. We are quite convinced that the preservation of the cough reflex alone constitutes one of the greatest advantages of epidural anesthesia, as the incidences of postoperative spreads, atelectasis, and aspiration pneumonias are reduced to a minimum.

Paralysis of the thoracolumbar outflow of the sympathetics also constitutes a great advantage of epidural anesthesia. As a result of this, the body remains warm and dry with a minimum of fluid loss, thus preserving the normal electrolyte balance of the body. Peripheral vasodilatation occurs, but this is partly neutralized by the administration of ephedrine. It is interesting to note that although a gradual drop in blood pressure occurs during operation, the increase in pulse rate is very slight. An average drop in blood pressure of 32 mm. systolic and 20 mm. diastolic with an average increase in pulse rate of 9.6 per minute was noted in the 100 cases. In twenty-eight cases, a gradual rise of the blood pressure, reaching a peak in about twenty minutes after completion of the injection, followed by a gradual drop was noted. None of our patients received a transfusion or an infusion in the operating room.

We have also noted a definite decrease in capillary bleeding as contrasted to general anesthesia with gas.

Postoperatively, it is gratifying to the surgeon to see a patient who has just undergone a major thoracic operation having little if any discomfort and able to help himself off the operating table. The analgesia following the anesthetic was noted to vary from two to twelve hours, averaging between five and six hours. Diets can be increased much more rapidly than with any other anesthetic. Two of these patients who underwent a thoracoplasty the day before Thanksgiving ate and enjoyed their turkey dinner the following day.

In eighty-one of the 100 patients the blood pressures were stabilized within one-half to two hours after operation. The remaining nineteen had various

degrees of shock; that is, their blood pressures were unstable for periods up to seventy-two hours. Five of these patients died, and their causes of death are tabulated along with their operative risk in Table VI. It will be noted that the anesthetic was not responsible for any of these deaths.

TABLE VI. ANALYSIS OF DEATHS

| NO. | SEX | AGE | OPERATION | RISK | COMMENTS |
|---|---|---|---|---|---|
| 1 | M | 57 | Exploratory Thoracotomy | IV | Died second postoperative day; autopsy, extensive carcinoma of left lung, pleura, kidneys. |
| 2 | F | 25 | Thoraco I | IV | Died fifth postoperative day; myocardial failure and pulmonary insufficiency; (V.C. 650 c.c.) |
| 3 | F | 43 | Thoraco III | III | Died thirty-second postoperative day; uremia. |
| 4 | F | 56 | Thoraco II | IV | Died second postoperative day; autopsy, hemorrhage from subscapular space filled pleural cavity through pleural tear |
| 5 | M | 62 | Pneumonectomy | III | Died 6 hr. postoperative; autopsy, massive intrathoracic hemorrhage. |

Vomiting was noted in thirty-three patients postoperatively. Eleven of these ceased vomiting after changing from morphine to some other drug, and in one it was due to sulfamerazine. These figures also include those patients who gagged and vomited after violent coughing spells.

Two patients had a mild degree of abdominal distention and in one it was moderate.

Twenty patients required twenty-seven catheterizations, averaging 1.3 times per patient, all within the first twelve hours after operation.

One patient had a moderate headache and another had a severe headache lasting three days. This latter patient experienced a similar headache following a previous nitrous oxide anesthesia, and a slight headache following a subsequent epidural anesthesia.

Of the sixty-five patients, nineteen had previous or subsequent surgery under nitrous oxide anesthesia. On questioning these nineteen patients, fourteen, or 74 per cent, preferred the epidural anesthetic, four preferred gas, and one was noncommital.

## COMPLICATIONS

Injection of the anesthetic agent into the subarachnoid space is the most serious error that can occur because of the high dosages used in epidurals as contrasted to the subarachnoid spinal anesthesias. This error can be avoided by careful observance of the technique. Fortunately, we have not had any cases in which this accident has occurred. Too rapid absorption of the anesthetic from the epidural space may cause varying degrees of toxic reactions. This, however, may be prevented to a large degree by the addition of adrenalin to the solution and the administration of ephedrine.

## CONCLUSION

In surgery of the lung, pleural cavity, or the chest wall, the ideal anesthesia should aim at fulfilling certain criteria, namely:

1. It should be relatively easy to administer with a minimum of discomfort to the patient
2. Should be relatively nontoxic
3. Should provide for maximum oxygenation of the cardiorespiratory system that may be further embarrassed by operative manipulations
4. Should not contribute to shock
5. Should permit various degrees of positive pressure to a collapsed lung
6. Should be uninflammable if the use of the cautery is anticipated
7. Should permit evacuation of the bronchopulmonary secretions, preferably by preserving the cough reflex
8. Should assure minimum discomfort during the immediate postoperative course and should not alter nor delay the physiological process of healing.

There are many distinct advantages of epidural anesthesia in thoracic surgery when compared with the other forms of anesthesia now in use. It is superior to general gas anesthesia as it is much less toxic, having little effect on the heart, lungs, or kidneys; does not inhibit the cough reflex, and provides maximum oxygenation of the respiratory system with minimum deviation from the normal physiology during surgery. It can be given to those extremely poor risk patients who cannot tolerate another form of general anesthesia.

It is superior to local anesthesia, as a single puncture suffices, thus saving both time and discomfort. The patients are more comfortable and there is no distortion of the tissues nor delay in healing. It can be used in an infected field as empyema, lung abscess, or in cases with infected skin or subscapular space following a previous thoracoplasty.

In 1942, Schaffner and Found[14] reported the use of a high subarachnoid spinal anesthesia in 335 cases of thoracoplasty. There were no serious complications, although a high subarachnoid block sufficient for a first stage thoracoplasty requires anesthetizing the sixth cervical nerve. The margin of safety between accomplishing this and affecting the medulla is quite small. No such margin exists in epidural anesthesia in which the anesthetic agent, as we have emphasized, cannot reach the medulla. Furthermore, the potential danger of infecting the meninges is not present with an epidural anesthesia.

Compared with the three types of anesthesia mentioned above, the postoperative course with those cases in which epidural anesthesias have been used are in general much smoother and the patients are more comfortable.

There are, however, some disadvantages in its use. It requires a somewhat difficult technique. However, this is easily overcome by one experienced in performing spinal punctures. Three of us administered the epidurals, one of us in only three cases, all three of which had excellent anesthesias. Slightly more time is necessary; at least thirty minutes being required after the administration of the anesthetic until the operation can be started. Although

some patients are psychologically unsuited for this type of anesthesia, this factor is of minor importance as the epidural can be supplemented by other forms of anesthesia.

The only contraindications to its use, we believe, are mechanical obstacles to its administration and hypersensitivity to the anesthetic agents used in epidurals. Calcification of the interspinous or yellow ligaments, obliteration of the epidural space, or infection in the region of the space may be obstacles to its use. With a positive allergic history, skin testing with the agents to be used is recommended.

After an analysis and comparison of the various forms of anesthesias, we are of the opinion that epidural anesthesia most closely approaches the ideal anesthesia for chest surgery.

## SUMMARY

1. A brief history, physiology, and technique of administration of epidural anesthesia are discussed.

2. A series of 100 thoracic operations performed on sixty-six patients at the Missouri State Sanatorium is presented.

3. The results of these anesthesias are analyzed.

4. Comparison is made of the various types of anesthesias now being used in thoracic operations with epidural anesthesia.

5. Advantages and disadvantages of epidural anesthesia are presented.

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## ADDENDUM

Since this paper was submitted for publication, epidural anesthesia has been administered in 203 additional cases with results paralleling those given in this paper.

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